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FLUID DYNAMIC ANALYSIS OF HYDRAULIC RAM IV

(USER'S MANUAL FOR PRESSURE WAVE GENERATION MODEL)

NAVAL WEAPONS CENTER, CHINA LAKE, CALIFORNIA

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FLUID DYNAMIC ANALYSIS OF HYDRAULIC RAM IV

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Final Report

E.A. Lundstrom
W.K. Fung

October 1976

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This report presents a theory for modeling the pressure wave generated by a penetrating projectile in fluid. Assumptions and limitation of the model are discussed. The computer program and sample problem listing also are presented.

FOREWORD

This report summarizes the results of research performed by the Naval Weapons Center, China Lake, CA. The work was conducted between July 1972 and December 1974, and Dr. E.A. Lundstrom and Mr. W.K. Fung were the Project Engineers.

The work was sponsored by JTCG/AS and Naval Air Systems Command Air Tasks A303-510A/26C/OW4736-0000 and A330-330E/216B/1F32-432-308, as part of a 3-year TEAS (Test and Evaluation Aircraft Survivability) program. The TEAS program was funded by DDR&E/ODDT&E. The effort was conducted under the direction of the JTCG/AS Technology R&D Subgroup as part of TEAS element 5.1.1.11, *Hydraulic Ram Program*. Current effort in this area supported by JTCG/AS includes *Hydraulic Ram Fluid-Structure*.

DISCLAIMER

The estimates in this report are not to be construed as an official position of any of the Services or of the Joint DARCOM/NMC/AFLC/AFSC Commanders.

NOTE

Information and data contained in this document are based on the reports available at the time of preparation, and the results may be subject to change.

CONTENTS

INTRODUCTION

During penetration of an aircraft fuel cell, bullets and other high speed projectiles generate intense pressure waves. Response of the fuel cell walls to these pressure waves can be catastrophic failure due to severe fracturing of entrance and exit cell walls. This phenomenon, termed hydraulic ram, is of particular importance to the survivability of U.S. military aircraft.

A computer program was developed by NWC (Naval Weapons Center) which calculates pressure waves generated by projectiles in a fluid. The fluid mechanics of hydraulic ram were developed as described in a previous report by NWC.[1] The purpose of this document is to provide information for the *Pressure Wave Generation Mode* in the application of the computer code, *Hydraulic Ram Program - Version One (HRP-VI).*

THEORETICAL CONSIDERATIONS

To calculate fluid pressures, it is necessary to know the velocity, rate of kinetic energy loss, and time of projectile arrival as functions of distance along the trajectory. Estimates of these quantities can be obtained by using a simple model of the bullet behavior.

The bullet is assumed to travel in a straight line, and its deceleration is described by Newton's Second Law.

$$m \frac{dV}{dt} = -D \tag{1}$$

where

m = bullet mass

V = bullet velocity

t = time

D = drag force

The drag force can be expressed as

$$D = \frac{1}{2} \rho V^2 A_0 C_D \tag{2}$$

[1]Naval Weapons Center. *Fluid Dynamic Analysis of Hydraulic Ram* by E. A. Lundstrom. China Lake, CA, NWC, July 1971. (NWC TP 5227, publication UNCLASSIFIED.)

where

ρ = fluid density

V = bullet velocity

C_D = drag coefficient of the bullet

A_o = projected frontal area of an unyawed bullet

Noting that

$$V = \frac{dx_b}{dt} \tag{3}$$

where x_b = bullet position along the trajectory, equations 1 and 2 can be combined, yielding

$$\frac{dV}{dx_b} = -\beta V_b \tag{4}$$

Where the velocity decay coefficient, β, is defined as

$$\beta = \frac{1}{2m} \rho C_D A_o \tag{5}$$

the rate of kinetic energy loss, dE/dx_b, where $E = 1/2mV^2$ can be expressed as

$$\frac{dE}{dx_b} = -mV \frac{dV}{dx_b} \tag{6}$$

Combining equations 4 and 6 yields

$$\frac{dE}{dx_b} = m\beta V^2 \tag{7}$$

For tumbling bullets, β is a function of x_b.

In this model the bullet is presumed to enter the test cell with 0 degree yaw and continue in this attitude with a constant drag coefficient until it reaches a distance, x_1, where it begins to tumble. The bullet becomes fully tumbled at a distance, x_2, and continues in this attitude with a constant drag coefficient. However, as evidenced from experimental results,[2] the bullet will impact the cell with 0 degree yaw and continue to tumble along its trajectory for a number of cycles before assuming a stable attitude. The model has an option

[2]Naval Weapons Center. *Fluid Dynamic Analysis of Hydraulic Ram III* by E. A. Lundstrom and W. K. Fung. China Lake, CA, NWC, October 1974. (JTCG/AS-74-T-015, publication UNCLASSIFIED.)

to include this continuous tumbling of the bullet. The coefficients, β_1 and β_2, are associated with the 0-degree yaw and tumbled attitudes, and the value β_3 is associated with the stern-first attitude. For simplicity it was assumed that the tumbling proceeds at a constant rate along the trajectory (Figure 1); that is

$$x_2 - x_1 = x_3 - x_2 = x_4 - x_3 = \ldots \tag{8}$$

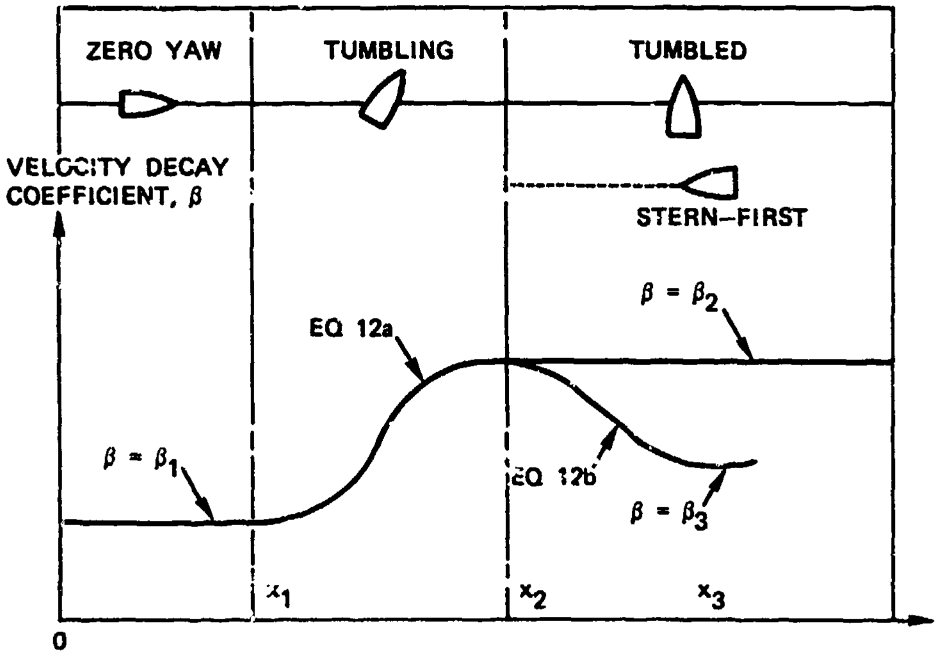

Figure 1. Bullet Orientation Versus Distance Along the Bullet Trajectory.

While the bullet is tumbling, i.e., $x_1, < x_b, < x_2$, β varies radically as a function of x_b. This variation can be expressed in general form as

$$\beta = \beta_1 + (\beta_2 - \beta_1)\, f(Y) \tag{9}$$

where

$$Y = \frac{x_b - x_1}{x_2 - x_1} \tag{10}$$

while

$$f(0) = 0$$

$$f(1) = 1$$

An empirical function of the following form was used.

$$f(Y) = \left[1/2 - 1/2 \cos (Y)\right]^n \tag{11}$$

The exponent, n = 3, is varied (see Footnote 2) yielding the following equations, for $x_1 < x_b < x_2$

$$\beta(x_b) = \beta_1 + (\beta_2 - \beta_1) \left\{1/2 - 1/2 \cos\left[\frac{x_b - x_1}{x_2 - x_1}\right]\right\}^3 \tag{12a}$$

for $x_2 < x_b < x_3$

$$\beta(x_b) = \beta_2 + (\beta_3 - \beta_2) \left\{1/2 - 1/2 \cos\left[\frac{x_b - x_2}{x_3 - x_2}\right]\right\}^3 \tag{12b}$$

When β is constant, equations 3 and 4 can be integrated directly. In the region $0 < x_b < x_1$, where $\beta = \beta_1$, the initial conditions are $V = V_o$ and $t = 0$. The integration then yields

$$V_b = V_o\, e^{-\beta_1 x_b} \tag{13}$$

and

$$t_b = \frac{1}{\beta_1}\left[\frac{1}{V_b} - \frac{1}{V_o}\right] \tag{14}$$

and equation 7 yields

$$\frac{dE}{dx_b} = m\beta_1 V_b^2 \tag{15}$$

In the region of tumbling, $x_1 < x_b < x_2$, algebraic expressions cannot be found; therefore, a numerical integration method is used for the model.

For stripping of bullet jackets from the AP (armor piercing) core of the API (armor-piercing incendiary) ammunition, a crude method for incorporating the jacket energy deposition was developed. The projectile penetrates the fluid for a distance, x_s, where the jacket strips. The kinetic energy of the jacket and incendiary material are calculated at that point. The energy deposition of the AP core is calculated in the normal manner except that values of β appropriate to the core must be used. The energy deposition of the jacket is assumed to be exponential and is added to that of the core. The equation for total energy deposition is

$$\frac{dE}{dx_b} = m_c\beta_c V_b^2 + a\frac{E_{js}}{\beta_j}\, e^{-\beta_j(x_b - x_s)} \tag{16}$$

$$E_{js} = 1/2\, m_j V_s^2 \tag{17}$$

where

m_j = mass of jacket

V_s = velocity of bullet at stripping location

m_c = mass of core

a = a constant found to be 1/3 (Footnote 2)

Because of the mathematical difficulties introduced by the wall boundary conditions, a simple model (Figure 2) is used which neglects the wall effects.

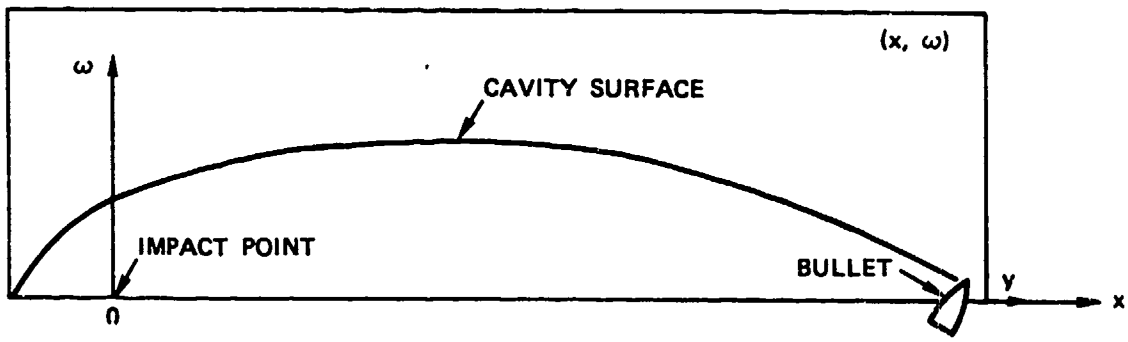

Figure 2. Model of Drag Phase of Hydraulic Ram.

The bullet shown in Figure 2 is initially stationary in an infinite body of fluid until t = 0. Then the bullet is impulsively accelerated to an initial velocity of V_o. At times, $t > 0$, the bullet moves with a velocity, V, in a straight line along the axis. It is assumed that the flow field can be described in terms of a potential function, ϕ, which satisfies the wave equation.

$$\nabla^2\phi = \frac{1}{c^2}\frac{\partial^2\phi}{\partial t^2} \tag{18}$$

where c = speed of sound in the fluid.

Then, the fluid velocity, $\vec{u}$, is expressed as

$$\vec{u} = \nabla\phi \tag{19}$$

and the Bernoulli equation yields

$$P = P_o - \rho\frac{\partial\phi}{\partial t} - 1/2\rho u^2 \tag{20}$$

where

P = total fluid pressure

P_o = ambient pressure

ρ = fluid density

$u = |\vec{u}|$

The boundary conditions for equation 18 are that the fluid velocity is tangential to the projectile surface and that $P = P_c$ on the cavity surface, where P_c denotes the pressure in the cavity. It is assumed that P_c is constant throughout the cavity; hence, the problem is to determine the pressure as a function of time at any arbitrary point (x,ω) where, as shown in Figure 2, ω is the perpendicular distance of this point from the x axis.

The problem is further simplified by ignoring the boundary conditions and then approximating the effect of the bullet and cavity on the fluid by the action of a line of sources distributed along the bullet trajectory. Then, the resulting flow field is symmetric about the x axis, and the potential due to these sources can be expressed as

$$\phi(x,\omega,t) = - \int_{o}^{X_b(\tau)} \frac{\zeta(\xi,\tau)}{r} \, d\xi \tag{21}$$

where

ξ = distance along the trajectory

r = distance between points ξ and (x,ω)

ζ = source strength at ξ

For the finite sound speed, the integral must be evaluated along the line $\tau + r/c$ = constant, where τ is the retarded time given by $\tau = t - r/c$. The integration path is included in the time space representation shown in Figure 3. Using equation 14, the time of bullet arrival, t_b, on the trajectory as a function of the bullet position, x_b, can be determined. However, the results of the theory are not considered to be valid during the cavity collapse; therefore, the lower limit in this integral can be taken as zero. The upper limit, X_b, denotes the projectile position when $\tau = t_b$.

The source strength, ζ, is estimated by a method based on the conservation of energy. It is assumed that the flow is confined to a section, dx, as shown in Figure 4.

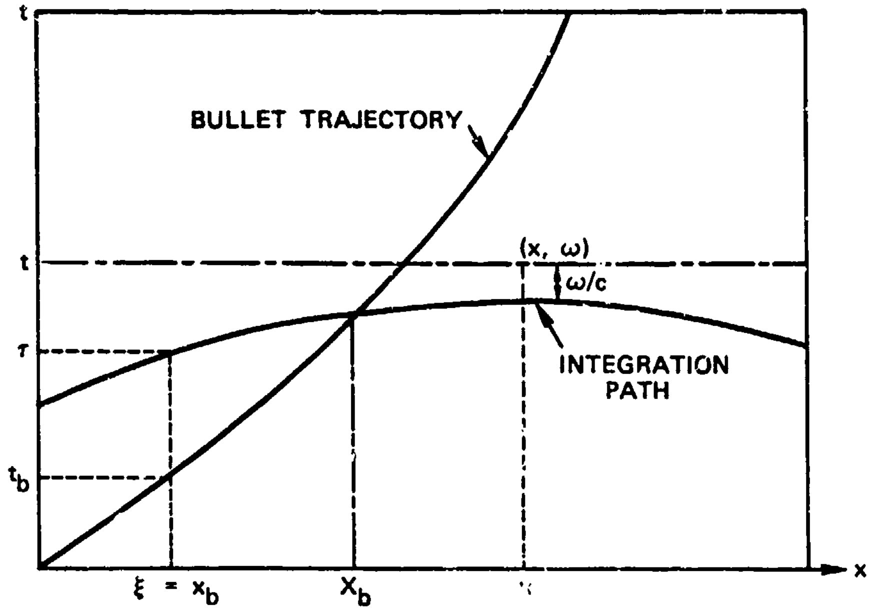

Figure 3. Integration Path of Integral in Equation 21 on the Time-Space Plane.

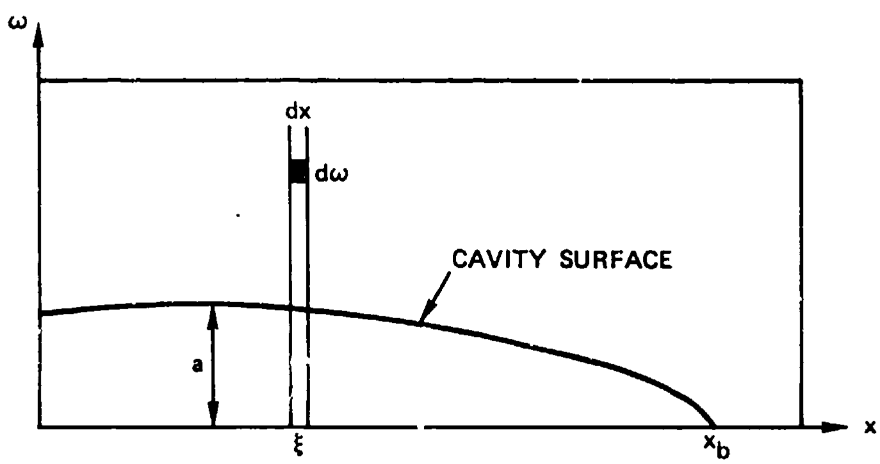

Figure 4. Flow Model for Estimating Cavity Growth and Source Strength Variation.

The fluid velocity in this section is then

$$u = \frac{2\zeta(\xi,t)}{\omega} \tag{22}$$

At the cavity radius, $\omega = a$ and $u = da/dt$ so

$$\zeta = 1/2a\,\frac{da}{dt} \tag{23}$$

Following Birkoff's theory (Footnote 3), the kinetic energy, dK, of the fluid in this section within a radius, Ω, is

$$dK = \left[\pi\rho \int_0^{\Omega} u^2 \omega\, d\omega\right] dx \tag{24}$$

with equation 22 and integrating

$$dK = 4\pi\rho N\zeta^2 dx \tag{25}$$

where

$$N = \ell n(\Omega/a)$$

Since the upper limit, Ω, cannot be infinite due to the physical impossibility of allowing dK to be infinite, Ω will be assumed to be finite. Because the value of N varies slowly as a function of Ω, it can be treated as a constant. This is justified for the special case in which a bullet is traveling with a constant velocity, since the correct cavity shape is obtained for constant values of the quantity Ω/a in the 15 to 30 range. Physically, this step can be rationalized by considering the neglected influence of the noncylindrical divergence of the flow.

The work, dW, done by the difference between the ambient and cavity pressure is

$$dW = \pi(P_O - P_C)a^2 dx \tag{26}$$

The energy, $d\epsilon$, deposited by the projectile in the fluid at dx is

$$d\epsilon = \left(\frac{dE}{dx_b}\right)_{\xi} dx \tag{27}$$

with equations 15 and 16 showing the expression for dE/dx_b as a function of the distance along the trajectory.

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[3]Birkoff, G., and E. H. Zarantonello. *Jets, Wakes, and Cavities*. New York, Academic Press, 1957.

The conservation of energy can be expressed by the relation

$$d\epsilon = dK + dW \tag{28}$$

and with equations 25, 26, and 27, it becomes

$$\left(\frac{dE}{dx_b}\right)_\xi dx = 4\pi\rho\zeta^2 N dx + \pi(P_o - P_c)a^2 dx \tag{29}$$

Defining

$$A^2 = \frac{\left(\frac{dE}{dx_b}\right)_\xi}{\pi(P_o - P_c)} \tag{30}$$

$$B^2 = \frac{P_o - P_c}{\rho N} \tag{31}$$

and simplifying, the energy balance yields the expression

$$\zeta = \pm 1/2B\sqrt{A^2 - a^2} \tag{32}$$

Eliminating ζ from equation 32, with equation 23

$$a\frac{da}{dt} = \pm B\ \sqrt{A^2 - a^2} \tag{33}$$

With boundary condition a = 0, at the time of projectile arrival, t_b, integration of equation 33 yields

$$\pm\ \sqrt{A^2 - a^2} = A - B(t - t_b) \tag{34}$$

where, according to equation 32

$$\zeta = 1/2\left[BA - B^2(t - t_b)\right] \tag{35}$$

The cavity behavior reaches a maximum radius when da/dt = 0. From equation 33, this radius is A, and from equation 34, the maximum radius occurs at time, t_m, at

$$t_m = t_b + \frac{A}{B} \tag{36}$$

The effects of the walls were neglected, so equations 30 and 31 give only the upper bounds for A and B; hence the source strength, equation 35, will be increasingly inaccurate as the cavity approaches its maximum inside an actual fuel cell.

Now, the pressure field resulting from the line of sources can be calculated. Substituting equation 35 for the source strength in equation 21 yields

$$\phi(x,\omega,t) = -1/2B \int_{0}^{X_b(\tau)} \frac{1}{r} \left\{ A(\xi) - B\left[t - \frac{r}{c} - t_b(\xi)\right]\right\} d\xi \tag{37}$$

Note that the retarded time τ in equation 21 was replaced by $t - r/c$.

To compute the pressure, the terms in Bernoulli's equation (equation 20) must be evaluated. The term, $\partial\phi/\partial t$, in Bernoulli's equation can be expressed in a simple form by using Leibnitz's rule for the differentiation of integrals. Equation 37 becomes (see Appendix A)

$$\frac{\partial\phi}{\partial t} = -1/2\left[\frac{BA_b}{R_b}\,\frac{\partial X_b(\tau)}{\partial t}\right] + 1/2\,B^2 \int_{0}^{X_b(\tau)} \frac{d\xi}{r} \tag{38}$$

where R_b is the distance between the bullet and the point (x,ω) and A_b denotes the value of A, evaluated at X_b. The chain rule for differentiation gives

$$\frac{\partial X_b(\tau)}{\partial t} = \frac{\partial X_b(\tau)}{\partial \tau}\,\frac{\partial \tau}{\partial t} \tag{39}$$

where

$$\frac{\partial X_b}{\partial \tau} = V \tag{40}$$

where V is the bullet velocity evaluated at X_b, and since

$$\frac{\partial \tau}{\partial t} = 1 - \frac{1}{c}\,\frac{\partial R_b(\tau)}{\partial t} = 1 + \frac{1}{c}\,\frac{x - X_b}{R_b}\,\frac{\partial X_b(\tau)}{\partial t} \tag{41}$$

equation 39 becomes

$$\frac{\partial X_b(\tau)}{\partial t} = V\left[1 + \frac{1}{c}\,\frac{x - X_b}{R_b}\,\frac{\partial X_b(\tau)}{\partial t}\right] \tag{42}$$

Solving for $\partial X_b(\tau)/\partial t$ gives

$$\frac{\partial X_b(\tau)}{\partial t} = \frac{V}{1 - \frac{V}{c}\frac{x - X_b}{R_b}} \tag{43}$$

With equation 43 and solving the integral, equation 38 becomes

$$\frac{\partial \phi}{\partial t} = -1/2\frac{BA_b}{R_b}\frac{V}{1 - \frac{V}{c}\frac{x - X_b}{R_b}} + 1/2B^2 \ell n\left[\frac{x + R_o}{x - X_b + R_b}\right] \tag{44}$$

where R_o is the distance between the impact point and the point (x,ω). In the same manner the fluid velocity components, u_x in the x direction and u_ω in the ω direction, can be derived as

$$u_x = \frac{\partial \phi}{\partial x} = 1/2\frac{BA_b}{R_b}\frac{\frac{V}{c}\frac{x - X_b}{R_b}}{1 - \frac{V}{c}\frac{x - X_b}{R_b}}$$

$$+ 1/2B \int_0^{X_b(\tau)} \left\{A(\xi) - B\left[t - t_b(\xi)\right]\frac{x - \xi}{r^3}\right\} d\xi \tag{45}$$

$$u_\omega = \frac{\partial \phi}{\partial \omega} = 1/2\frac{BA_b}{R_b}\frac{\frac{V}{c}\frac{\omega}{R_b}}{1 - \frac{V}{c}\frac{x - X_b}{R_b}}$$

$$+ 1/2B\omega \int_0^{X_b} \left\{A(\xi) - B\left[t - t_b(\xi)\right]\right\}\frac{1}{r^3}\, d\xi \tag{46}$$

It should be noted that functions A(ξ) and $t_b(\xi)$ depend on the tumbling behavior of the bullet. Hence, the integrals in equations 45 and 46 cannot be evaluated explicitly. Noting the reaction that

$$u^2 = u_x{}^2 + u_\omega{}^2 \tag{47}$$

the pressure field can be obtained by substituting equations 44, 45, 46, and 47 into Bernoulli's equation 20.

Waves reflected from rigid plane walls can be calculated exactly by means of the method of images. The boundary condition for a rigid wall is that the normal component of the fluid velocity, u_n, vanishes at the wall. Pressure generated by the bullet has been approximated by a line of sources (or sinks). The boundary condition at the wall can be satisfied by adding the pressure due to a mirror image line of sources (or sinks) as illustrated in Figure 5.

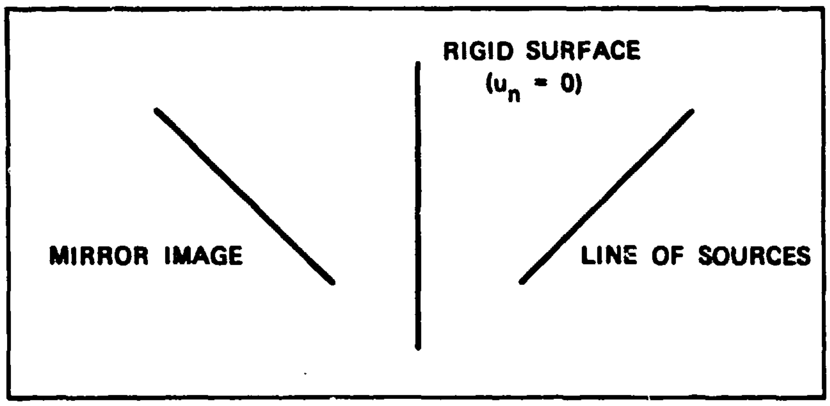


Figure 5. Geometry of Method of Images for a Single Rigid Surface.

The boundary condition for a free surface is P = 0 at the surface. A negative mirror image satisfies this condition to the extent that

$$\left|\frac{\partial\phi}{\partial t} + 1/2u_t{}^2\right| >> \left|1/2u_n{}^2\right| \tag{48}$$

where u_t and u_n are the tangential and normal fluid velocity components at the surface. Equation 48 is satisfied for most conditions during the initial phase of hydraulic ram.

The method of images is easily extended to calculate reflections from the walls of rectangular volumes. The result is a three-dimensional rectangular array of images. The number of images in the array is determined by the number of wave reflections to be included in the calculation. A method for automatic generation of the image array coordinates was developed, and its use is discussed in Appendix B.

The walls of aircraft fuel cells are neither free nor rigid. However, due to their typically light construction, waves reflected from these walls can be approximated by means of the method of images for free surfaces. The effect of the inertial properties of the fuel cell walls on wave reflections is discussed in Footnote 1.

SUMMARY

The pressure is calculated according to Bernoulli's equation

$$P - P_O = -\rho\frac{\partial\phi}{\partial t} - 1/2\rho u^2$$

The first term is dominant far from the bullet, while the second term is important closer to the bullet. The boundary condition $P = 0$ at the surface is satisfied by the method of images for the $\rho\ \partial\phi/\partial t$ term only. It is suggested that the full equation be used to calculate incident pressure waves on the wall.

Although the action of the cavity behind the bullet is accounted for in the fluid model, the absence of fluid within the cavity is ignored. Therefore, in the absence of external surfaces, the calculated pressure will be positive outside the cavity, zero on the cavity surface, and negative within the cavity. Indeed, the pressure will go to minus infinity as the cavity axis is approached. In addition, the cavity presents an additional surface for reflecting pressure waves. Thus, waves arising from the bullet, reflecting from the fluid volume surface, and then *reflecting from the cavity surface* are not accounted for.

The presence of the bounding free surfaces of the fluid volume often produces large negative pressures within the fluid, thus producing bulk cavitation. These phenomena are not included in the fluid model.

It is suggested that the pressure calculated by the program be truncated at negative pressures; that is, if

$$P \leq O$$

then

$$P = 0$$

This process assumed that bulk cavitation always occurred and also automatically accounted for the absence of fluid in the cavity.

Since the bullet is modeled by a line of sources, the pressure goes to infinity at the bullet. It is suggested that the pressure calculated by the program be truncated at the stagnation pressure of the bullet.

PROGRAM DESCRIPTION

PROGRAM USAGE

The program consists of one short main program and six subroutines (TRAJ, MIRROR, IMAGE, TV, INTERP, and IPLOT). The basic function of this computer code is to generate hydraulic ram induced pressure-time curves at user specified points within a body of fluid. The code allows the use of the method of images to account for wave reflections in a rectangular volume bounded by free surfaces.

DESCRIPTION OF SUBROUTINES

TRAJ

The primary task of this subroutine is to compute the following quantities as a function of bullet distances along the trajectory.

1. Time of bullet arrival
2. Bullet velocity
3. Maximum cavity radius
4. Time of cavity collapse
5. Drag parameter as a function of time

MIRROR

This subroutine is responsible for computing the following:

1. Total pressure at a point (specified by the user) as a function of time
2. Pressure due to the time derivative of the velocity potential
3. Total fluid velocity as a function of time
4. X, Y, and Z components of fluid velocity

IMAGE

This subroutine computes the coordinates of the projectile entrance/exit points in the three-dimensional image volumes with respect to the actual volume.

TV

This subroutine computes the value of the velocity decay parameter, then integrates the equations of motion to obtain bullet velocity as a function of time.

INTERP

This subroutine interpolates the following quantities between discrete points along the bullet trajectory.

1. The distance of the bullet along its trajectory as a function of retarded time
2. The velocity of the bullet as a function of retarded time
3. The radius of the attached cavity as a function of retarded time

IPLOT

The function of this subroutine is to generate graphic presentation of the total pressure versus time at each point in the fluid body specified by the user. The plotting routines are available only on the NWC UNIVAC 1110.

DESCRIPTION OF PARAMETERS

NJOB – a variable which indicates the number of different complete data sets to be operated on by the code during one full run.

NP – a variable which specifies the total number of points at which pressure (as a function of time) is to be computed.

TMAX – the maximum time, in milliseconds, for which pressure is to be calculated at each point.

DT – time increment, in milliseconds, which specifies the timewise spacing of computed pressures.

IPLOT – a plot request variable which equals 1/0 for plot/no plot. Note that this variable controls plotting through routines available only on the NWC UNIVAC 1108.

XW(I,J) – this array contains the coordinates of the points at which pressure is to be computed. XW(I,1) = X, XW(I,2) = Y, XW(I,3) = 2 (see Appendix C).

LM(1), LM(2), LM(3) – image array limiters in the negative direction of the X, Y, and Z axes (see Appendix B).

LP(1), LP(2), LP(3) – image array limiters in the positive direction of the X, Y, and Z axes (see Appendix B).

XC(1), XC(2), XC(3) – the coordinates of that point which specifies the X, Y, and Z dimensions of the rectangular volume into which the projectile is fired.

X(1), X(2), X(3) – the X, Y, and Z coordinates of the entrance point of the projectile on the surface of the rectangular volume.

X(4), X(5), X(6) – the X, Y, and Z coordinates of the exit point of the projectile from the surface of the rectangular volume.

XMASS(1) – bullet mass, pound (Appendix D)

XMASS(2) – penetrator mass, pound

XMASS(3) – jacket mass, pound

AREA(1) – bullet presented area, normal attitude, in^2

AREA(2) – bullet presented area, tumbled attitude, in^2

AREA(3) – penetrator presented area, normal attitude, in^2

AREA(4) – penetrator presented area, tumbled attitude, in^2

AREA(5) – jacket presented area, tumbled attitude, in^2

AREA(6) – bullet stern-first presented area, in^2

DRAG(1) – coefficient of drag for bullet, normal attitude

DRAG(2) – coefficient of drag for bullet, tumbled attitude

DRAG(3) – coefficient of drag for penetrator, normal attitude

DRAG(4) – coefficient of drag for penetrator, tumbled attitude

DRAG(5) – coefficient of drag for jacket, tumbled attitude

DRAG(6) – coefficient of drag for bullet stern-first, normal attitude

DENS – fluid density, lb/in^3

PO – ambient pressure, psi

PC – cavity pressure, psi, normally taken to be zero

C – sound speed in fluid, ft/sec

BC – constant, normally taken to be 0.434

VEL – initial bullet velocity, ft/sec

DX – distance increment along trajectory, inch

NT – a variable such that NT = 0/1 means that the bullet does not tumble/does tumble

XSTRIP – distance along the trajectory that the bullet begins to strip

XTUM – distance along the trajectory that the bullet begins to tumble, inch (Appendix E)

DXTUM – distance required for the bullet to become fully tumbled, inch. If NT = 0, XTUM and DXTUM can be arbitrary

NE – is a variable such that NE = 0/1 means bullet does not exit tank/does exit tank

XE – distance along the trajectory where the bullet exits the volume, inch. If NE = 0, XE can be arbitrary

XMAX – maximum length of trajectory through volume, inch. Dimension statements limit XMAS to 300*DX

EN – exponent which specifies power law followed by the drag function (EN = 3.0 in general)

EFRACT – a factor related to bullet stripping (EFRACT = 3.0 in general)

NCTUM A VARIABLE SUCH THAT NCTUM = 0,1,2 – means bullet does not continuously tumble/bullet continuously tumbles/bullet continuously tumbles for one cycle

BS, OMEGA – parameter not in use for this version set equal to 1

NSTRIP – a variable such that NSTRIP = 0/1 means that bullet does not strip/bullet does strip

INPUT FORMATS

Card type	Format	Contents
1	I1	NJOB
2	I3	NP (limit to 1,000)
3	2F10.5,I1	TMAX, DT, IPLOT
4A . . . 4Z	3F10.5	XW(I,J) (limit to 300)
5	6I2,3F10.5	LM(1), LM(2), LM(3), LP(1), LP(2), LP(3), XC(1), XC(2), XC(3)

Card type	Format	Contents
6	3F10.5	X(1), X(2), X(3)
7	3F10.5	X(4), X(5), X(6)
8	3F5.5, 6F6.4	XMAS(1), XMAS(2), XMAS(3), AREA(1), AREA(2), AREA(3), AREA(4), AREA(5), AREA(6)
9	6F6.4	DRAG(1), DRAG(2), DRAG(3), DRAG(4), DRAG(5), DRAG(6)
10	5F9.4	DENS, PO, PC, C, BC
11	2F9.4	VEL, DX
12	I1,F9.1,4F10.0	NT, OMEGA, XSTRIP, XTUM, DXTUM
13	I1,F9.1	NE, XE
14	F10.0	XMAX
15	3F6.3,2I6	EN, BS, EFRACT, NCTUM, NSTRIP
16A . . . 16Z	2A6	AA(1), AA(2)

TEST PROBLEM

The following test problem was taken from Footnote 2. The calculations were performed on a UNIVAC 1110 computer.

1. Number of points, pressure-time history to be calculated: 5

2. Location of the points at which pressure is to be calculated:

   a. (36, 30, 6)
   b. (36, 30, 12)
   c. (36, 30, 18)
   d. (36, 30, 24)
   e. (36, 30, 30)

3. Size of tank: 60- x 60- x 60-inch projectile

4. Entrance point: (30.50, 31.50, 0.0)

5. Projectile exit point: (30.50, 31.50, 36.00)

6. Type of projectile: 12.7 mm API

7. Projectile velocity: 2,797.50 ft/sec

8. Fluid in tank: water

9. Maximum time for calculation: 1 msec

10. Minimum distance for calculation: 35 inches

11. Image array used:

    a. LM(1, 2, 3) = (0, 0, 1)
    b. LP(1, 2, 3) = (0, 0, 0)

12. Tumbling behavior:

    a. XTUM = 5.13 inches
    b. DXTUM = 15.66 inches
    c. Projectile tumbles continuously

13. Time increment: DT = 0.0125 msec

14. Distance increment: DX = 0.2 inch

PROGRAM LISTING AND TEST PROBLEM OUTPUT (pages 20 through 58)

```
C      ******HYDRAULIC RAM PROGRAM - VERSION ONE******
       DIMENSION A(3,300)
       COMMON/PLOT,ASIGN(300),X0(300),Y0(300),Z0(300),X1(300),Y1(300),Z1(
      1300),NS,DT,TMAX,NP,XW(300,3)
       COMMON/IDINFO/ID(6)
       DATA ID/36H 4023  W. FUNG   3681  HRP OUTPUT
       READ(5,1000) NJOB
       DO 1 KK=1,NJOB
       READ(5,2001)NP
       READ(5,3001)TMAX,DT,IPLOT
 3001  FORMAT(2F10.5,I1)
       DO2I=1,NP
       READ(5,1001)(XW(I,J),J=1,3)
 2     CONTINUE
 1001  FORMAT(3F10.5)
 2001  FORMAT(I3)
 1000  FORMAT(I1)
       CALL IMAGE(NS)
       CALL TRAJ(A,B,DX,XE,NE,C,DENS,JXE,JMAX)
       CALL MIRROR(A,B,DX,XE,NE,C,DENS,JXE,JMAX)
     1 CONTINUE
       CALL EXIT
       END




       SUBROUTINE TRAJ (A,B,DX,XE,NE,C,DENS,JXE,JMAX)
       DIMENSION XMASS(3),BETA(7),AREA(6),DRAG(6),A(3,300)
       COMMON/XSTRIP/XSTRIP,NCTUM
       READ(5,6000)(XMASS(I),I=1,3),(AREA(I),I=1,6)
 6000  FORMAT(3F5.5, 6F6.4)
       READ(5,6001) (DRAG(I),I=1,6)
6001   FORMAT(6F6.4)
       READ(5,1000) DENS,PO,PC,C,BC
       READ(5,1000) VEL,DX
 1000  FORMAT(5F9.4)
       READ(5,1001)NT,OMEGA,XSTRIP,XTUM,DXTUM
       READ(5,1001) NE,XE
 1001  FORMAT(I1,F9.1,4F10.1)
       READ(5,1002) XMAX
 1002  FORMAT(F10.0)
       READ(5,1003) EN,BS,EFRACT,NCTUM,NSTRIP
C    NSTRIP=1,0       BULLET STRIP TRUE/FALSE
C NCTUM=0,1,2        NO CONTINUOUS TUMBLING,CONTINUOUS TUMBLING,TUMBLE FOR 1 CYCLE
1003   FORMAT(3F6.3,2I6)
       NI=1
       DO5I=1,5
       IF(I.EQ.3)NI=2
       IF(I.EQ.5)NI=3
       BETA(I)=.5/XMASS(NI)*DENS*AREA(I)*DRAG(I)
 5     CONTINUE
       BETA(7)=.5/XMASS(2) *DENS*AREA(6)*DRAG(6)
       BETA(6)=.5/XMASS(1) *DENS*AREA(6)*DRAG(6)
       WRITE(6,1700)EN,BS,EFRACT,NCTUM,NSTRIP,NT,XTUM,DXTUM,XSTRIP,(XMASS
      $(I),I=1,3),(AREA(I),I=1,6),(DRAG(I),I=1,6),(BETA(I),I=1,7),VEL,DEN
      $S,PO,PC,C,BC
 1700  FORMAT(1H1,/////,54X,'HYDRAULIC RAM PROGRAM VERSION ONE MOD ONE',/
      $///,2X,'EN          =',F10.5,/,2X,'BS          =',F10.5,/,2X,'EFRACT   =
      $',F10.5,/,2X,'NCTUM     =',I10,/,2X,'NSTRIP    =',I10,/,2X,'NT
      $ =',I10,/,2X,'XTUM      =',F10.5,/,2X,'DXTUM     =',F10.5,/,2X,'XSTRI
      $P    =',F10.5,/,2X,'XMASS(3) =',3F10.5,/,2X,'AREA(6)   =',6F10.5,/,2
      $X,'DRAG(6)   =',6F10.5,/,2X,'BETA(7)   =',7F10.5,/,2X,'VEL        =',F
      $10.5,/,2X,'DENS       =',F10.5,/,2X,'PO          =',F10.5,/,2X,'PC
      $ =',F10.5,/,2X,'C           =',F10.5,/,2X,'BC          =',F10.5,///)
       WRITE(6,303)
```

```
303 FORMAT(1H1)
    WRITE(6,304)
304 FORMAT(//2X,'DISTANCE(IN)',10X,'TIME(MSEC)',8X,'VELOCITY(FT/SEC)
   1 ,6X,'CAVITY RADIUS(IN)',4X,'CAVITY COLLAPSE(MSEC)',4X,'BETA'/)
    JS=-10
    C=C*.012
    VEL=VEL*.012
    DENS=DENS/.0003864
    B=(P0-PC)/DENS*BC
    B=SQRT(B)
    JMAX=XMAX/DX+.001
    JXE=XE/DX+.001
    IGNAT=0
    BETAX=BETA(1)
    D=XMASS(1)/(3.14159265*(P0-PC)*.00038641)
    D=SQRT(D)
    DXT=XTUM+DXTUM+DX
C INITIAL VALUES
    NPAGE=0
    DV=EXP(-BETAX*DX)
    V=VEL/DV
    T=-(1.-DV)/BETAX/VEL
401 IF(NSTRIP.EQ.0) GOTO 403
    JS=XSTRIP/DX+0.5
    AK=JS
    XSTRIP=AK*DX
403 JJ=-1
  8 JJ=JJ+1
    TEMX=JJ
    TEMX=TEMX*DX
    IF(JJ.NE.JS)GO TO 402
    IF(NSTRIP.EQ.0) GOTO 402
    BETA(1)=BETA(3)
    BETA(2)=BETA(4)
    BETA(6)=BETA(7)
    D=XMASS(2)/(3.14159265*(P0-PC)*.00038641)
    D=SQRT(D)
    D5=.5*XMASS(3)*V*V*BETA(5)/3.14159265/(P0-PC)/.0003864
    D5=D5/EFRACT
    IF(TEMX.LT.XTUM)BETAX=BETA(1)
    IF(TEMX.GE.XTUM+DXTUM)BETAX=BETA(2)
    DV=EXP(-BETAX*DX)
    IGNAT=1
402 IF(NE.EQ.0)GO TO 9
    IF(JJ.GT.JXE) RETURN
  9 IF(TEMX.GT.XMAX) RETURN
    IF(NT.EQ.0) GO TO 10
    IF(TEMX.LT.DXT.AND.TEMX.GT.XTUM)GO TO 11
    IF(NCTUM.EQ.1.AND.TEMX.GT.XTUM) GOTO 11
10  V=V*DV
    T=T+(1.-DV)/BETAX/V
    IF(NT.EQ.0) GO TO 13
    GO TO 12
11  CALL TV(T,V,BETAX,BETA,DX,TEMX,XTUM,DXTUM,EN,NCTUM )
12  ART=XTUM+DXTUM
    IF(TEMX.GE.ART.AND.TEMX.LE.DXT)DV=EXP(-BETA(2)*DX)
 13 XX=TEMX
    AM=D*V*SQRT(BETAX)
    IF(IGNAT.EQ.1)GO TO 1103
    GO TO 9494
1103 CONTINUE
    AM=SQRT(AM*AM+D5*EXP((XSTRIP-XX)*BETA(5)))
```

```
 9494 CONTINUE
      AM=AM*BS
      TM=2.*AM/B
      TMM=TM+T
      A(1,JJ+1)=V
      A(2,JJ+1)=T
      A(3,JJ+1)=AM
      VFT=V/.012
      IF(NIRO.NE.0) GOTO 8
      WRITE(6,305) XX,T,VFT,AM,TMM,BETAX
  305 FORMAT(2X,F10.4,11X,
     1 F10.4,12X,F9.4,14X,F9.4,12X,F9.4,9X,F9.5)
      NPAGE=NPAGE+1
      IF(NPAGE.LT.48) GO TO 8
      WRITE(6,303)
      WRITE(6,304)
      NPAGE=0
      GO TO 8
      END
```

```
      SUBROUTINE MIRROR(A,B,DX,XE,NE,C,DENS,JXE,JMAX)
      DIMENSIONX(300),W(300),RO(300),RI(300),XI(300),YI(300),ZI(300)
      DIMENSIONEW(1000),EX(1000),DEX2(1000),DEW2(1000),A(3,300) ,L(1000)
      DIMENSIONTIG(500),PIG(500)
      COMMONIPLOT,ASIGN(300),XO(300),YO(300),ZO(300),X1(300),Y1(300),Z1(
     1300),NS,DT,TMAX,NP,XW(300,3)
      DO 6 JK=1,NP
      XP=XW(JK,1)
      YP=XW(JK,2)
      ZP=XW(JK,3)
      DO 1 K=1,NS
C  COORDINATE TRANSFORMATION
      RO(K)=(XP-XO(K))**2+(YP-YO(K))**2+(ZP-ZO(K))**2
      RO(K)=SQRT(RO(K))
      RI(K)=(X1(K)-XO(K))**2+(Y1(K)-YO(K))**2+(Z1(K)-ZO(K))**2
      RI(K)=SQRT(RI(K))
      X(K)=((X1(K)-XO(K))*(XP-XO(K))+(Y1(K)-YO(K))*(YP-YO(K))
     1      +(Z1(K)-ZO(K))*(ZP-ZO(K)))/RI(K)
      W(K)=RO(K)**2-X(K)**2
      W(K)=SQRT(W(K))
      XI(K)=X(K)/RI(K)*(X1(K)-XO(K))+XO(K)
      YI(K)=X(K)/RI(K)*(Y1(K)-YO(K))+YO(K)
      ZI(K)=X(K)/RI(K)*(Z1(K)-ZO(K))+ZO(K)
C  INITIAL VALUES
      NPAGE=0
      EX(K)=0.
      EW(K)=0.
      DEX2(K)=0.
      DEW2(K)=0.
      L(K)=0
    1 CONTINUE
C  PRINT INPUT
      WRITE(6,1004)
 1004 FORMAT(1H1,///50X,'PRESSURE CALCULATED AT POINT')
      WRITE(6,1005)  XP,YP,ZP
 1005 FORMAT(//39X,'X=',F7.2,'(IN)',5X,'Y=',F7.2,'(IN)',5X,'Z=',F7.2,
     1  '(IN)')
      WRITE(6,1006)  (K,X(K),W(K),XO(K),YO(K),ZO(K),XI(K),YI(K),ZI(K),
     1  ASIGN(K),K=1,NS)
```

```
 1006 FORMAT(//55X,'SOURCE COORDINATES'//,30X,'X',10X,'W',9X,'XO',9X,
     1  'YO',9X,'ZO',9X,'X1',9X,'Y1',9X,'Z1'/(18X,I2,8F11.3,F8.0))
C  PRINT HEADING
      WRITE(6,1007)
 1007 FORMAT(1H1,/,11X,'T(MSEC)',4X,'P(PSI)',5X,'PPHI',6X,'U(FT/SEC)'
     1  ,5X,'UX',9X,'UY',9X,'UZ'//)
C  FIND INTIAL TIME
      RMIN=RO(1)
      DO 2 K=1,NS
      IF(RO(K).LT.RMIN) RMIN=RO(K)
    2 CONTINUE
      JT=RMIN/C/DT
      T=JT
      T=T*DT-DT*2.
      IMU=0
    3 T=T+DT
      IF(T.GE.TMAX)GO TO 666
      SUMUX=0.
      SUMUY=0.
      SUMUZ=0.
      SPPHI=0.
C  COMPUTE PRESSURE AND VELOCITY AT TIME T
      DO 5 K=1,NS
C  FIRST FIND PROJECTILE PARAMETERS FOR SOURCE K
      CALL INTERP(XX,V,AM,L,K,A,X,*,T,C,DX,JMAX,NE,JXE)
      IF(L(K).EQ.0) GO TO 5
C  CHECK FOR EXIT AND XMAX
      IF(L(K).GT.JMAX) GO TO 6
      IF(NE.EQ.0) GO TO 4
      IF(L(K).LE.JXE) GO TO 4
      V=0.
      XX=XE
      AM=0.
    4 CONTINUE
C  COMPUTE VELOCITY DUE TO SOURCE K
      R=(X(K)-XX)**2+W(K)**2
      R=SQRT(R)
      DTDX=1./(1.-V/C*(X(K)-XX)/R)
      DEX1=(AM-B*R/C)*V*DTDX/R**3
      DEW1=DEX1
      DEX1=DEX1*(X(K)-XX)-B*(1./R-1./RO(K))
      DEW1=DEW1*W(K)+B/W(K)*((X(K)-XX)/R-X(K)/RO(K))
      EX(K)=EX(K)+.5*(DEX1+DEX2(K))*DT
      EW(K)=EW(K)+.5*(DEW1+DEW2(K))*DT
      DEX2(K)=DEX1
      DEW2(K)=DEW1
      UU=F*AM*V/C*DTDX/R**2
      UXX=UU*(X(K)-XX)+R*EX(K)
      UW=UU*W(K)+R*EW(K)
      UX=(UW/W(K)*(XP   -XI(K))+UXX/R1(K)*(X1(K)-XO(K)))*0.5
      UY=(UW/W(K)*(YP   -YI(K))+UXX/R1(K)*(Y1(K)-YO(K)))*0.5
      UZ=(UW/W(K)*(ZP   -ZI(K))+UXX/R1(K)*(Z1(K)-ZO(K)))*0.5
C  COMPUTE PRESSURE (PPHI ) DUE TO SOURCE K
      PPHI=F*AM/R*V*DTDX-B*B*ALOG((X(K)+RO(K))/(X(K)-XX+R))
      PPHI=PPHI*0.5
C  SUM VELOCITIES
      SUMUX=SUMUX+UX*ASIGN(K)
      SUMUY=SUMUY+UY*ASIGN(K)
      SUMUZ=SUMUZ+UZ*ASIGN(K)
C  SUM PRESSURES
      SPPHI=SPPHI+PPHI*ASIGN(K)
    5 CONTINUE
      UX=SUMUX/.012
      UY=SUMUY/.012
      UZ=SUMUZ/.012
      PPHI=SPPHI*DENS
      U2=UX*UX+UY*UY+UZ*UZ
```

```
      P=PPHI-.5*DENS*U2*.000144
      IMU=IMU+1
      TIG(IMU)=T
      PIG(IMU)=P
      U=SQRT(U2)
C   PRINT OUTPUT
      WRITE(6,1008)  T,P,PPHI,U,UX,UY,UZ
 1008 FORMAT(6X,9F11.3)
      NPAGE=NPAGE+1
      IF(NPAGE.LT.49) GO TO 3
      WRITE(6,1007)
      NPAGE=0
      GO TO 3
  666 CONTINUE
       SSSUM=0.0
       DO 20 IK=2,IMU
   20 SSSUM=SSSUM+PIG(IK)
      SSSUM=(PIG(1)*0.5+SSSUM-PIG(IMU)*0.5)*0.0125
      WRITE(6,1009)SSSUM
1009  FORMAT(//,1H ,'TOTAL IMPULSE (PSI-MSEC) =',F15.7)
      IF(IPLOT.EQ.1)GO TO 68
      GO TO 69
 68   CALL IGPLOT(TIG,PIG,IMU,XP,YP,ZP)
 69   CONTINUE
    6 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE INTERP(XX,V,AM,L,K,A,X,W,T,C,DX,JMAX,NE,JXE)
      DIMENSION A(3,300),L(1000),X(1000),W(1000)
    1 M=L(K)+1
      IF(L(K).GE.JMAX) RETURN
      IF(NE.EQ.0) GO TO 2
      IF(L(K).GT.JXE) RETURN
    2 XJ=L(K)
      XX=XJ*DX
      R=(X(K)-XX)**2+W(K)**2
      R=SQRT(R)
      TAU=A(2,M)+R/C
      IF(T.LT.TAU) GO TO 3
      L(K)=L(K)+1
      GO TO 1
    3 IF(L(K).EQ.0) RETURN
C    INTERPOLATE
      RR=(X(K)-XX+DX)**2+W(K)**2
      RR=SQRT(RR)
      TTAU=A(2,M-1)+RR/C
      DL=(T-TTAU)/(TAU-TTAU)
      XX=XX-DX+DL*DX
      V=A(1,M-1)+DL*(A(1,M)-A(1,M-1))
      AM=A(3,M-1)+DL*(A(3,M)-A(3,M-1))
      RETURN
      END
```

```
      SUBROUTINETV(T,V,BETAX,BETA,DX,TEMX,XTUM,DXTUM,EN,NCTUM)
      DIMENSION BETA(7)
      VT=V
      TT=T
      BB=BETAX
      DUM=XTUM+DXTUM*2.
      IF(TEMX.GE.DUM.AND.NCTUM.EQ.2) GOTO 3
      IF(TEMX.GE.XTUM+DXTUM.AND.NCTUM.EQ.0) GOTO 4
      YY=(TEMX-XTUM)/DXTUM
      NY=YY/2.
      AY=NY
      YY=YY-AY*2.
      YPI=YY*3.1416
      YPI=ABS(YPI)
      ABCD=DUM+2.*DXTUM
      IF(TEMX.GE.ABS(ABCD)) GOTO 5
      ABCD=DUM+DXTUM
      IF(TEMX.GE.ABS(ABCD)) GOTO 6
      IF(TEMX.GE.XTUM+DXTUM) GOTO 5
    6 BETAX=BETA(1)+(BETA(2)-BETA(1))*(.5*(1.-COS(YPI)))**EN
      GOTO 3
 4    BETAX=BETA(2)
      GOTO 3
    5 BETAX=BETA(6)+(BETA(2)-BETA(6))*(.5*(1.-COS(YPI)))**EN
    3 CONTINUE
      V=VT*EXP(-(BETAX+BB)*DX/2.)
      T=TT+(1./V+1./VT)*DX/2.
      RETURN
      END




      SUBROUTINE IMAGE(I)
      DIMENSIONLM(3),LP(3),X(3),XC(3),XP(350,3),A(3),B(3),C(3),SN(3),
     1SNJ(3)
      COMMONIPLOT,ASIGN(300),X0(300),Y0(300),Z0(300),X1(300),Y1(300),Z1(
     1300),NS,DT,TMAX,NP,XW(300,3)
      READ(5,99)LM(1),LM(2),LM(3),LP(1),LP(2),LP(3),XC(1),XC(2),XC(3)
      N=1
 99   FORMAT(6I2,3F10.5)
        WRITE(6,999)
      WRITE(6,1000)
      WRITE(6,1001)XC(1),XC(2),XC(3)
      WRITE(6,4999)
 14   READ(5,98)(X(K),K=1,3)
 98   FORMAT(3F10.5)
C DETERMINE IF LM(K) ARE EVEN OR ODD
C SN(K)=-1 ODD8 SN(K)=+1 EVEN
 999  FORMAT(1H1,60X,'IMAGE DATA')
 1000 FORMAT(///,56X,'CORNER COORDINATES',//,48X,'XC(1)',10X,'XC(2)',10X
     1,'XC(3)')
 1001 FORMAT(/,47X,F7.2,8X,F7.2,8X,F7.2)
 4999 FORMAT(///,1X,'POINT NO.',6X,'A(1)',6X,'A(2)',6X,'A(3)',5X,'IMAGE
     1 TYPE',10X,'X0',10X,'Y0',10X,'Z0',10X,'X1',10X,'Y1',10X,'Z1')
      DO 1K=1,3
      ALM=LM(K)
      ALM=ABS(ALM)/2.
      LLM=ALM
      BLM=LLM
      DLM=ALM-BLM
      SN(K)=-1.
      IF(DLM.LT.0.1)SN(K)=1.
 1    CONTINUE
C COMPUTE POINT COORDINATES XP(I,K)
```

```
C...............................................................
      I=0
      JXM=LP(1)+LM(1)+1
      JYM=LP(2)+LM(2)+1
      JZM=LP(3)+LM(3)+1
C INITIALIZEAND START THE X DIRECTION DO LOOP
      A(1)=-LM(1)-1
      SNJ(1)=-SN(1)
      DO5JX=1,JXM
      SNJ(1)=-SNJ(1)
      A(1)=A(1)+1.
C INITIALIZE AND START THE Y DIRECTION DO LOOP
      A(2)=-LM(2)-1
      SNJ(2)=-SN(2)
      DO 4JY=1,JYM
      A(2)=A(2)+1.
      SNJ(2)=-SNJ(2)
C     INITIALIZE AND START THE Z DIRECTION DO LOOP
      A(3)=-LM(3)-1
      SNJ(3)=-SN(3)
      DO3JZ=1,JZM
      A(3)=A(3)+1.
      SNJ(3)=-SNJ(3)
CADVANCE THE POINT COUNTER I AND COMPUTE THE XYZ COORDINATES (K=123) OF
C POINT I
      I=I+1
      DO2K=1,3
      B(K)=(1.+SNJ(K))/2.
      C(K)=(1.-SNJ(K))/2.
      XP(I,K)=A(K)*XC(K)+B(K)*X(K)+C(K)*(XC(K)-X(K))
 2    CONTINUE
      ASIGN(I)=SNJ(1)*SNJ(2)*SNJ(3)
      IF(N.EQ.2)WRITE(6,100)I,A(1),A(2),A(3),ASIGN(I),XO(I),YO(I),ZO(I),
     1(XP(I,K),K=1,3)
 100  FORMAT(/,3X,I5,7X,F5.1,4X,F5.1,4X,F5.1,6X,F5.1,9X,F10.5,5(2X,F10.5
     1))
  3   CONTINUE
  4   CONTINUE
 5    CONTINUE
      GO TO (6,9),N
 6    DO83JJ=1,I
      XO(JJ)=XP(JJ,1)
      YO(JJ)=XP(JJ,2)
      ZO(JJ)=XP(JJ,3)
 83   CONTINUE
      N=2
      GO TO 14
 9    DO84JJ=1,I
      X1(JJ)=XP(JJ,1)
      Y1(JJ)=XP(JJ,2)
      Z1(JJ)=XP(JJ,3)
 84   CONTINUE
      RETURN
      END




      SUBROUTINE IGPLOT(U,V,I,XA,YA,ZA)
      DIMENSIONB(4),C(6),D(5),E(5)
      DIMENSION A(1)
      DIMENSION Z(200)
      DIMENSIONU(1),V(1),X(500),Y(500)
      DIMENSIONAA(2)
      READ(5,690)AA(1),AA(2)
      IF(I.LE.5)GO TO 6969
```

```
 690  FORMAT(2A6)
      B(1)=6HNAVAL
      B(2)=6H WEAPO
      B(3)=6HNS  CE
      B(4)=5HNTER
      C(1)=6HADVANC
      C(2)=6HED SYS
      C(3)=6HTEMS B
      C(4)=6HRANCH,
      C(5)=6H CODE
      C(6)=6H 3014
      D(1)=6HAIRCRA
      D(2)=6HFT SUR
      D(3)=6HVIVABI
      D(4)=6HLITY P
      D(5)=6HROGRAM
      E(1)=6HRUN NO
      E(2)=6H. HRP-
      E(3)=6H-
      CALL MODESG (Z,0)
      DO 100 J=1,I
      X(J)=U(J)
      Y(J)=V(J)
  100 CONTINUE
      XMAX=X(1)
      XMIN=X(1)
      YMAX=Y(1)
      YMIN=Y(1)
      DO666ILK=1,I
      IF(X(ILK).LT.XMIN) XMIN=X(ILK)
      IF(X(ILK).GT.XMAX)XMAX=X(ILK)
      IF(Y(ILK).GT.YMAX)YMAX=Y(ILK)
      IF(Y(ILK).LT.YMIN)YMIN=Y(ILK)
 666  CONTINUE
      CALL OBJCTG (Z,0.,0.,4095.,3071.)
      CALL SUBJEG(Z,XMIN,YMIN,XMAX,YMAX)
      CALL GRAPHG(Z,I,X,Y,9,9HTIME--MS.,20,20HPRESSURE--LB./SQ.IN.,45,45
     1HPRESSURE VS. TIME PLOT--HYDRAULIC RAM PROGRAM)
      CALL POINTG (Z,I,X,Y)
      CALL LINESG(Z,I,X,Y)
      CALL SETSMG(Z,14,1.0)
      A(1)=6HX =
      CALL NUMBRG(Z,1535.,111.,-6,A(1))
      A(1)=6H     ,
      CALL NUMBRG(Z,1646.,111.,-6,A(1))
      A(1)=6HY =
      CALL NUMBRG(Z,1834.,111.,-6,A(1))
      A(1)=6H     ,
      CALL NUMBRG(Z,1945.,111.,-6,A(1))
      A(1)=6HZ =
      CALL NUMBRG(Z,2130.,111.,-6,A(1))
      CALL NUMBRG(Z,1627.,111.,5.1,XA)
      CALL NUMBRG(Z,1909.,111.,5.1,YA)
      CALL NUMBRG(Z,2222.,111.,5.1,ZA)
      CALL NUMBRG(Z,1858.,3036.,-24,B)
      CALL NUMBRG(Z,1708.,2981.,-36,C)
      CALL NUMBRG(Z,1748.,2891.,-30,D)
      CALL NUMBRG(Z,1816.,2711.,-14,E)
      CALL NUMBRG(Z,2168.,2711.,-12,AA)
      CALL SETSMG(Z,14,0.0)
      CALL PAGEG (Z,0,1,1)
      CALL EXITG (Z)
      WRITE(6,1069)AA(1),AA(2)
 1069 FORMAT(///,'*********DATA POINTER**********',/,'***THIS OUTPUT CO
     1MPLEMENTS IGS PLOT HRP - ',2A6)
 6969 CONTINUE
      RETURN
      END
```

IMAGE DATA

CORNER COORDINATES

XC(1)	XC(2)	XC(3)
60.00	90.00	60.00

POINT NO.	A(1)	A(2)	A(3)	IMAGE TYPE	X0	Y0	Z0	X1	Y1	Z1
1	.0	.0	-1.0	-1.0	30.50000	31.50000	.00000	30.50000	31.50000	-60.00000
2	.0	.0	.0	1.0	30.50000	31.50000	.00000	30.50000	31.50000	60.00000

HYDRAULIC RAM PROGRAM VERSION ONE MOD ONE

```
EN         =   3.00000
BS         =   1.00000
EFRACT     =   3.00000
NCTUM      =         1
NSTRIP     =         0
NT         =         1
XTUM       =   5.13000
DXTUM      =  15.66000
XSTRIP     =  35.00000
XMASS(3)   =    .10660     .06410    .04250
AREA(6)    =    .20460    1.03760    .14320    .70020   1.03760    .08550
DRAG(6)    =    .05000     .30000    .05000    .30000   1.00000    .82000
ZETA(7)    =    .00173     .05272    .00202    .05915    .44076    .01187    .01974
VEL        =2797.50000
DENS       =    .03610
PO         =  15.80000
PC         =    .00000
C          =4915.00000
BC         =    .43400
```

DISTANCE (IN)	TIME (MSEC)	VELOCITY (FT/SEC)	CAVITY RADIUS (IN)	CAVITY COLLAPSE (MSEC)	BETA
.0000	.0000	2797.4999	3.2938	24.3160	.001732
.2000	.0060	2796.5309	3.2927	24.3135	.001732
.4000	.0119	2795.5622	3.2915	24.3111	.001732
.6000	.0179	2794.5939	3.2904	24.3086	.001732
.8000	.0238	2793.6259	3.2893	24.3062	.001732
1.0000	.0298	2792.6582	3.2881	24.3037	.001732
1.2000	.0358	2791.6909	3.2870	24.3013	.001732
1.4000	.0418	2790.7239	3.2858	24.2988	.001732
1.6000	.0477	2789.7572	3.2847	24.2964	.001732
1.8000	.0537	2788.7909	3.2836	24.2940	.001732
2.0000	.0597	2787.8249	3.2824	24.2916	.001732
2.2000	.0657	2786.8593	3.2813	24.2891	.001732
2.4000	.0716	2785.8939	3.2802	24.2867	.001732
2.6000	.0776	2784.9289	3.2790	24.2843	.001732
2.8000	.0836	2783.9643	3.2779	24.2819	.001732
3.0000	.0896	2783.0000	3.2767	24.2795	.001732
3.2000	.0956	2782.0359	3.2756	24.2772	.001732
3.4000	.1016	2781.0723	3.2745	24.2748	.001732
3.6000	.1076	2780.1090	3.2733	24.2724	.001732
3.8000	.1136	2779.1460	3.2722	24.2700	.001732
4.0000	.1196	2778.1833	3.2711	24.2676	.001732
4.2000	.1256	2777.2210	3.2699	24.2653	.001732
4.4000	.1316	2776.2590	3.2688	24.2629	.001732
4.6000	.1376	2775.2974	3.2677	24.2606	.001732
4.8000	.1436	2774.3361	3.2665	24.2582	.001732
5.0000	.1496	2773.3751	3.2654	24.2559	.001732
5.2000	.1556	2772.4144	3.2643	24.2535	.001732
5.4000	.1616	2771.4541	3.2632	24.2512	.001732
5.6000	.1676	2770.4941	3.2620	24.2489	.001732
5.8000	.1736	2769.5344	3.2609	24.2466	.001732
6.0000	.1797	2768.5751	3.2598	24.2444	.001732
6.2000	.1857	2767.6161	3.2587	24.2424	.001732
6.4000	.1917	2766.6573	3.2577	24.2411	.001732
6.6000	.1977	2765.6988	3.2569	24.2408	.001733
6.8000	.2038	2764.7404	3.2563	24.2426	.001733
7.0000	.2098	2763.7818	3.2561	24.2475	.001734
7.2000	.2158	2762.8228	3.2567	24.2575	.001736
7.4000	.2219	2761.8629	3.2582	24.2748	.001739
7.6000	.2279	2760.9013	3.2611	24.3024	.001743
7.8000	.2339	2759.9370	3.2660	24.3443	.001750
8.0000	.2400	2758.9689	3.2734	24.4052	.001759
8.2000	.2460	2757.9949	3.2842	24.4906	.001772
8.4000	.2521	2757.0130	3.2991	24.6072	.001789
8.6000	.2581	2756.0202	3.3193	24.7623	.001812
8.8000	.2641	2755.0129	3.3459	24.9644	.001843
9.0000	.2702	2753.9868	3.3800	25.2225	.001882
9.2000	.2763	2752.9366	3.4230	25.5461	.001932
9.4000	.2823	2751.8561	3.4762	25.9450	.001994

DISTANCE (IN)	TIME (MSEC)	VELOCITY (FT/SEC)	CAVITY RADIUS (IN)	CAVITY COLLAPSE (MSEC)	BETA
9.6000	.2884	2750.7378	3.5410	26.4289	.002071
9.8000	.2944	2749.5732	3.6185	27.0073	.002164
10.0000	.3005	2748.3524	3.7100	27.6887	.002277
10.2000	.3066	2747.0641	3.8164	28.4806	.002412
10.4000	.3126	2745.6957	3.9387	29.3894	.002571
10.6000	.3187	2744.2327	4.0774	30.4195	.002758
10.8000	.3248	2742.6593	4.2330	31.5741	.002976
11.0000	.3308	2740.9581	4.4056	32.8545	.003228
11.2000	.3369	2739.1100	4.5952	34.2604	.003517
11.4000	.3430	2737.0942	4.8016	35.7899	.003845
11.6000	.3491	2734.8883	5.0243	37.4398	.004217
11.8000	.3552	2732.4685	5.2626	39.2056	.004635
12.0000	.3613	2729.8093	5.5160	41.0817	.005102
12.2000	.3674	2726.8839	5.7833	43.0618	.005620
12.4000	.3735	2723.6644	6.0638	45.1385	.006193
12.6000	.3797	2720.1215	6.3563	47.3040	.006823
12.8000	.3858	2716.2252	6.6597	49.5498	.007511
13.0000	.3919	2711.9447	6.9728	51.8670	.008260
13.2000	.3981	2707.2487	7.2942	54.2462	.009071
13.4000	.4042	2702.1059	7.6228	56.6777	.009944
13.6000	.4104	2696.4848	7.9570	59.1516	.010880
13.8000	.4166	2690.3545	8.2957	61.6576	.011880
14.0000	.4228	2683.6846	8.6372	64.1852	.012943
14.2000	.4290	2676.4459	8.9802	66.7239	.014067
14.4000	.4353	2668.6106	9.3233	69.2628	.015251
14.6000	.4415	2660.1524	9.6650	71.7913	.016494
14.8000	.4478	2651.0474	10.0038	74.2986	.017792
15.0000	.4541	2641.2739	10.3382	76.7738	.019143
15.2000	.4604	2630.8131	10.6669	79.2064	.020541
15.4000	.4668	2619.6491	10.9883	81.5859	.021984
15.6000	.4731	2607.7696	11.3012	83.9020	.023466
15.8000	.4795	2595.1659	11.6041	86.1448	.024982
16.0000	.4860	2581.8330	11.8958	88.3047	.026526
16.2000	.4925	2567.7703	12.1751	90.3725	.028091
16.4000	.4990	2552.9812	12.4406	92.3396	.029671
16.6000	.5055	2537.4736	12.6915	94.1978	.031258
16.8000	.5121	2521.2598	12.9265	95.9396	.032845
17.0000	.5187	2504.3567	13.1449	97.5582	.034424
17.2000	.5254	2486.7853	13.3457	99.0474	.035987
17.4000	.5321	2468.5714	13.5283	100.4019	.037526
17.6000	.5389	2449.7446	13.6920	101.6170	.039032
17.8000	.5458	2430.3388	13.8362	102.6890	.040498
18.0000	.5526	2410.3917	13.9607	103.6148	.041916
18.2000	.5596	2389.9444	14.0651	104.3924	.043276
18.4000	.5666	2369.0414	14.1492	105.0203	.044571
18.6000	.5737	2347.7299	14.2130	105.4982	.045794
18.8000	.5808	2326.0597	14.2565	105.8262	.046937
19.0000	.5880	2304.0827	14.2798	106.0055	.047993

DISTANCE (IN)	TIME (MSEC)	VELOCITY (FT/SEC)	CAVITY RADIUS (IN)	CAVITY COLLAPSE (MSEC)	BETA
19.2000	.5953	2281.8526	14.2832	106.0379	.048956
19.4000	.6026	2259.4242	14.2670	105.9258	.049820
19.6000	.6100	2236.6531	14.2317	105.6725	.050579
19.8000	.6175	2214.1957	14.1777	105.2816	.051229
20.0000	.6251	2191.5078	14.1057	104.7574	.051765
20.2000	.6327	2168.8452	14.0162	104.1046	.052184
20.4000	.6404	2146.2626	13.9100	103.3285	.052484
20.6000	.6482	2123.8138	13.7879	102.4344	.052662
20.8000	.6561	2101.5506	13.6505	101.4283	.052717
21.0000	.6641	2079.5206	13.5005	100.3286	.052663
21.2000	.6722	2057.7641	13.3399	99.1511	.052511
21.4000	.6803	2036.3171	13.1694	97.9008	.052261
21.6000	.6885	2015.2136	12.9898	96.5831	.051916
21.8000	.6968	1994.4851	12.8017	95.2031	.051477
22.0000	.7052	1974.1610	12.6060	93.7661	.050947
22.2000	.7137	1954.2681	12.4032	92.2776	.050331
22.4000	.7223	1934.8303	12.1941	90.7427	.049630
22.6000	.7310	1915.8692	11.9794	89.1666	.048851
22.8000	.7397	1897.4038	11.7599	87.5546	.047998
23.0000	.7485	1879.4500	11.5361	85.9117	.047075
23.2000	.7574	1862.0214	11.3089	84.2427	.046090
23.4000	.7664	1845.1288	11.0787	82.5527	.045046
23.6000	.7755	1828.7803	10.8463	80.8461	.043952
23.8000	.7846	1812.9819	10.6123	79.1277	.042812
24.0000	.7939	1797.7363	10.3773	77.4019	.041634
24.2000	.8032	1783.0447	10.1418	75.6730	.040424
24.4000	.8126	1768.9057	9.9065	73.9451	.039189
24.6000	.8220	1755.3156	9.6718	72.2223	.037935
24.8000	.8316	1742.2689	9.4384	70.5086	.036669
25.0000	.8412	1729.7581	9.2067	68.8078	.035398
25.2000	.8508	1717.7738	8.9773	67.1236	.034126
25.4000	.8606	1706.3051	8.7505	65.4597	.032862
25.6000	.8704	1695.3398	8.5270	63.8194	.031609
25.8000	.8802	1684.8638	8.3072	62.2064	.030375
26.0000	.8901	1674.8623	8.0915	60.6237	.029163
26.2000	.9001	1665.3192	7.8803	59.0748	.027979
26.4000	.9102	1656.2174	7.6741	57.5626	.026826
26.6000	.9203	1647.5393	7.4733	56.0902	.025709
26.8000	.9304	1639.2664	7.2782	54.6603	.024631
27.0000	.9406	1631.3798	7.0893	53.2758	.023596
27.2000	.9508	1623.8602	6.9068	51.9392	.022605
27.4000	.9611	1616.6880	6.7312	50.6528	.021660
27.6000	.9714	1609.8437	6.5626	49.4188	.020765
27.8000	.9818	1603.3076	6.4014	48.2391	.019918
28.0000	.9922	1597.0603	6.2478	47.1154	.019123
28.2000	1.0027	1591.0826	6.1019	46.0491	.018378
28.4000	1.0132	1585.3554	5.9640	45.0411	.017683
28.6000	1.0237	1579.8603	5.8340	44.0923	.017039

DISTANCE (IN)	TIME (MSEC)	VELOCITY (FT/SEC)	CAVITY RADIUS (IN)	CAVITY COLLAPSE (MSEC)	BETA
28.8000	1.0343	1574.5794	5.7121	43.2028	.016444
29.0000	1.0449	1569.4953	5.5982	42.3726	.015897
29.2000	1.0555	1564.5914	5.4923	41.6013	.015397
29.4000	1.0662	1559.8516	5.3942	40.8879	.014943
29.6000	1.0769	1555.2609	5.3038	40.2313	.014531
29.8000	1.0876	1550.6048	5.2209	39.6296	.014161
30.0000	1.0984	1546.4698	5.1451	39.0809	.013830
30.2000	1.1092	1542.2434	5.0762	38.5829	.013536
30.4000	1.1200	1538.1138	5.0137	38.1328	.013276
30.6000	1.1308	1534.0701	4.9574	37.7278	.013048
30.8000	1.1417	1530.1023	4.9068	37.3649	.012949
31.0000	1.1526	1526.2014	4.8614	37.0408	.012677
31.2000	1.1636	1522.3592	4.8206	36.7522	.012530
31.4000	1.1745	1518.5681	4.7846	36.4960	.012404
31.6000	1.1855	1514.6215	4.7524	36.2688	.012298
31.8000	1.1965	1511.1137	4.7236	36.0674	.012209
32.0000	1.2076	1507.4394	4.6979	35.8889	.012136
32.2000	1.2186	1503.7941	4.6749	35.7303	.012076
32.4000	1.2297	1500.1740	4.6543	35.5888	.012027
32.6000	1.2409	1496.5757	4.6356	35.4621	.011988
32.8000	1.2520	1492.9963	4.6186	35.3477	.011957
33.0000	1.2632	1489.4337	4.6030	35.2437	.011934
33.2000	1.2744	1485.8859	4.5885	35.1462	.011915
33.4000	1.2856	1482.3510	4.5750	35.0596	.011902
33.6000	1.2969	1478.8281	4.5622	34.9765	.011892
33.8000	1.3082	1475.3161	4.5500	34.8977	.011885
34.0000	1.3195	1471.8143	4.5383	34.8223	.011880
34.2000	1.3308	1468.3219	4.5269	34.7495	.011876
34.4000	1.3422	1464.8387	4.5157	34.6785	.011874
34.6000	1.3536	1461.3642	4.5047	34.6089	.011873
34.8000	1.3650	1457.3983	4.4939	34.5404	.011872
35.0000	1.3764	1454.4407	4.4832	34.4725	.011872
35.2000	1.3879	1450.9915	4.4725	34.4052	.011872
35.4000	1.3994	1447.5505	4.4619	34.3383	.011871
35.6000	1.4109	1444.1177	4.4513	34.2716	.011871
35.8000	1.4225	1440.6930	4.4407	34.2052	.011871
36.0000	1.4341	1437.2765	4.4302	34.1391	.011871
36.2000	1.4457	1433.8681	4.4197	34.0731	.011871
36.4000	1.4573	1430.4677	4.4092	34.0074	.011871
36.6000	1.4690	1427.0754	4.3987	33.9419	.011871
36.8000	1.4807	1423.6911	4.3883	33.8765	.011871
37.0000	1.4924	1420.3149	4.3779	33.8114	.011871
37.2000	1.5041	1416.9467	4.3675	33.7465	.011871
37.4000	1.5159	1413.5864	4.3572	33.6819	.011871
37.6000	1.5277	1410.2342	4.3469	33.6175	.011871
37.8000	1.5396	1406.8898	4.3366	33.5534	.011872
38.0000	1.5514	1403.5533	4.3263	33.4898	.011872
38.2000	1.5633	1400.2246	4.3162	33.4267	.011873

DISTANCE (IN)	TIME (MSEC)	VELOCITY (FT/SEC)	CAVITY RADIUS (IN)	CAVITY COLLAPSE (MSEC)	BETA
38.4000	1.5752	1396.9035	4.3061	33.3645	.011874
38.6000	1.5872	1393.5900	4.2962	33.3033	.011875
38.8000	1.5991	1390.2837	4.2865	33.2437	.011878
39.0000	1.6111	1386.9843	4.2771	33.1860	.011882
39.2000	1.6232	1383.6913	4.2680	33.1309	.011888
39.4000	1.6352	1380.4042	4.2594	33.0793	.011896
39.6000	1.6473	1377.1221	4.2513	33.0320	.011908
39.8000	1.6594	1373.8440	4.2440	32.9901	.011924
40.0000	1.6716	1370.5688	4.2376	32.9548	.011945
40.2000	1.6838	1367.2948	4.2323	32.9276	.011972
40.4000	1.6960	1364.0202	4.2282	32.9099	.012006
40.6000	1.7082	1360.7428	4.2257	32.9036	.012050
40.8000	1.7205	1357.4600	4.2250	32.9105	.012104
41.0000	1.7328	1354.1688	4.2263	32.9327	.012171
41.2000	1.7451	1350.8657	4.2300	32.9721	.012251
41.4000	1.7574	1347.5466	4.2363	33.0310	.012349
41.6000	1.7698	1344.2070	4.2455	33.1116	.012464
41.8000	1.7822	1340.8420	4.2580	33.2162	.012601
42.0000	1.7947	1337.4458	4.2740	33.3469	.012760
42.2000	1.8071	1334.0122	4.2939	33.5058	.012945
42.4000	1.8197	1330.5344	4.3178	33.6950	.013159
42.6000	1.8322	1327.0051	4.3460	33.9160	.013402
42.8000	1.8448	1323.4162	4.3788	34.1705	.013679
43.0000	1.8574	1319.7594	4.4163	34.4597	.013991
43.2000	1.8700	1316.0254	4.4586	34.7844	.014342
43.4000	1.8827	1312.2049	4.5057	35.1452	.014732
43.6000	1.8954	1308.2877	4.5577	35.5421	.015165
43.8000	1.9082	1304.2635	4.6146	35.9748	.015642
44.0000	1.9210	1300.1217	4.6763	36.4425	.016165
44.2000	1.9338	1295.8514	4.7425	36.9441	.016735
44.4000	1.9467	1291.4413	4.8130	37.4778	.017355
44.6000	1.9596	1286.8804	4.8876	38.0416	.018024
44.8000	1.9726	1282.1575	4.9660	38.6330	.018744
45.0000	1.9856	1277.2615	5.0477	39.2491	.019515
45.2000	1.9987	1272.1817	5.1323	39.8867	.020336
45.4000	2.0119	1266.9077	5.2193	40.5424	.021207
45.6000	2.0250	1261.4296	5.3083	41.2125	.022127
45.8000	2.0383	1255.7381	5.3987	41.8930	.023095
46.0000	2.0516	1249.8246	5.4899	42.5797	.024108
46.2000	2.0649	1243.6814	5.5814	43.2685	.025165
46.4000	2.0784	1237.3017	5.6726	43.9551	.026263
46.6000	2.0919	1230.6799	5.7629	44.6352	.027398
46.8000	2.1055	1223.8116	5.8517	45.3045	.028567
47.0000	2.1191	1216.6934	5.9385	45.9587	.029766
47.2000	2.1329	1209.3236	6.0226	46.5937	.030990
47.4000	2.1467	1201.7019	6.1036	47.2055	.032234
47.6000	2.1606	1193.8293	6.1809	47.7901	.033493
47.8000	2.1746	1185.7085	6.2541	48.3440	.034762

DISTANCE (IN)	TIME (MSEC)	VELOCITY (FT/SEC)	CAVITY RADIUS (IN)	CAVITY COLLAPSE (MSEC)	BETA
48.0000	2.1887	1177.3437	6.3226	48.8637	.036034
48.2000	2.2024	1168.7409	6.3860	49.3460	.037304
48.4000	2.2172	1159.9075	6.4439	49.7881	.038564
48.6000	2.2317	11[illegible]0.8523	6.4960	50.1871	.039810
48.8000	2.2462	1141.5960	6.5420	50.5409	.041033
49.0000	2.2609	1132.1205	6.5815	50.8475	.042228
49.2000	2.2757	1122.4691	6.6144	51.1050	.043388
49.4000	2.2906	1112.6466	6.6404	51.3122	.044505
49.6000	2.3056	1102.6688	6.6595	51.4680	.045575
49.8000	2.3208	1092.5527	6.6715	51.5718	.046590
50.0000	2.3361	1082.3161	6.6764	51.6230	.047545
50.2000	2.3516	1071.9778	6.6741	51.6218	.048434
50.4000	2.3672	1061.5573	6.6647	51.5682	.049251
50.6000	2.3830	1051.0743	6.6483	51.4628	.049991
50.8000	2.3989	1040.5492	6.6250	51.3065	.050650
51.0000	2.4150	1030.0026	6.5948	51.1002	.051223
51.2000	2.4313	1019.4550	6.5581	50.8452	.051708
51.4000	2.4477	1008.9270	6.5150	50.5431	.052100
51.6000	2.4643	998.4368	6.4656	50.1956	.052398
51.8000	2.4811	988.0103	6.4104	49.8044	.052599
52.0000	2.4981	977.6609	6.3495	49.3717	.052703
52.2000	2.5152	967.4098	6.2830	48.8984	.052705
52.4000	2.5325	957.2770	6.2103	48.3790	.052568
52.6000	2.5500	947.2841	6.1315	47.8147	.052349
52.8000	2.5677	937.4517	6.0470	47.2083	.051989
53.0000	2.5856	927.7990	5.9571	46.5629	.051511
53.2000	2.6037	918.3442	5.8624	45.8814	.050918
53.4000	2.6219	909.1037	5.7631	45.1665	.050213
53.6000	2.6403	900.0927	5.6596	44.4212	.049401
53.8000	2.6589	891.3249	5.5524	43.6483	.048487
54.0000	2.6777	882.8124	5.4417	42.8503	.047476
54.2000	2.6967	874.5658	5.3281	42.0301	.046376
54.4000	2.7159	866.5942	5.2117	41.1900	.045192
54.6000	2.7352	859.9051	5.0929	40.3326	.043932
54.8000	2.7546	851.5047	4.9721	39.4601	.042603
55.0000	2.7743	844.3975	4.8495	38.5748	.041213
55.2000	2.7941	837.5969	4.7254	37.6787	.039770
55.4000	2.8141	831.0747	4.6002	36.7741	.038283
55.6000	2.8342	824.8615	4.4740	35.8626	.036759
55.8000	2.8545	818.9465	4.3471	34.9463	.035207
56.0000	2.8749	813.3281	4.2198	34.0269	.033635
56.2000	2.8955	808.0032	4.0923	33.1060	.032051
56.4000	2.9162	802.9678	3.9648	32.1852	.030463
56.6000	2.9370	798.2169	3.8375	31.2662	.028879
56.8000	2.9579	793.7447	3.7106	30.3504	.027306
57.0000	2.9790	789.5446	3.5843	29.4392	.025750
57.2000	3.0001	785.6090	3.4588	28.5340	.024220
57.4000	3.0214	781.9300	3.3343	27.6363	.022720

DISTANCE (IN)	TIME (MSEC)	VELOCITY (FT/SEC)	CAVITY RADIUS (IN)	CAVITY COLLAPSE (MSEC)	BETA
57.6000	3.0426	778.4988	3.2110	26.7474	.021257
57.8000	3.0642	775.3063	3.0891	25.8687	.019836
58.0000	3.0856	772.3429	2.9687	25.0015	.018461
58.2000	3.1074	769.5985	2.8500	24.1471	.017136
58.4000	3.1291	767.0629	2.7333	23.3070	.015865
58.6000	3.1506	764.7257	2.6186	22.4824	.014651
58.8000	3.1727	762.5762	2.5063	21.6747	.013497
59.0000	3.1945	760.6037	2.3964	20.8853	.012403
59.2000	3.2165	758.7975	2.2892	20.1157	.011372
59.4000	3.2385	757.1470	2.1848	19.3672	.010404
59.6000	3.2605	755.6415	2.0835	18.6413	.009499
59.8000	3.2826	754.2708	1.9854	17.9395	.008657
60.0000	3.3047	753.0246	1.8908	17.2631	.007878

PRESSURE CALCULATED AT POINT

X = 36.00 (IN) Y = 30.00 (IN) Z = 6.00 (IN)

SOURCE COORDINATES

	X	W	X0	Y0	Z0	X1	Y1	Z1	
1	-6.000	5.701	30.500	31.500	.000	30.500	31.500	-60.000	-1.
2	6.000	5.701	30.500	31.500	.000	30.500	31.500	60.000	1.

T (MSEC)	P (PSI)	PPHI	U (FT/SEC)	UX	UY	UZ
.125	.000	.000	.000	.000	.000	.000
.137	.000	.000	.000	.000	.000	.000
.150	174.856	174.908	2.782	2.018	-.550	1.834
.162	181.646	181.714	3.188	2.514	-.686	1.836
.175	166.076	186.164	3.611	3.027	-.826	1.787
.187	188.061	168.171	4.042	3.546	-.967	1.683
.200	187.667	187.802	4.472	4.056	-1.106	1.525
.212	185.099	185.260	4.894	4.547	-1.240	1.317
.225	160.691	180.880	5.301	5.009	-1.366	1.067
.237	174.801	175.019	5.688	5.435	-1.482	.785
.250	167.852	168.098	6.054	5.822	-1.588	.481
.262	160.191	160.467	6.396	6.168	-1.682	.165
.275	152.146	152.449	6.713	6.475	-1.766	-.157
.287	143.988	144.318	7.007	6.745	-1.839	-.477
.300	135.941	136.297	7.279	6.981	-1.904	-.790
.312	128.203	128.584	7.530	7.188	-1.960	-1.094
.325	120.950	121.355	7.765	7.371	-2.010	-1.386
.337	114.347	114.776	7.985	7.534	-2.055	-1.667
.350	108.543	108.995	8.196	7.684	-2.096	-1.937
.362	103.763	104.238	8.403	7.825	-2.134	-2.198
.375	100.104	100.602	8.609	7.961	-2.171	-2.454
.387	97.633	98.156	8.819	8.097	-2.208	-2.707
.400	96.603	97.153	9.037	8.237	-2.246	-2.962
.412	96.908	97.485	9.266	8.382	-2.286	-3.222
.425	98.606	99.214	9.508	8.533	-2.327	-3.488
.437	101.670	102.311	9.765	8.692	-2.371	-3.765
.450	105.905	106.583	10.037	8.858	-2.416	-4.054
.462	111.296	112.013	10.324	9.031	-2.463	-4.355
.475	117.520	118.279	10.625	9.207	-2.511	-4.669
.487	124.522	125.327	10.938	9.388	-2.560	-4.997
.500	131.974	132.827	11.262	9.569	-2.610	-5.336
.512	139.757	140.662	11.596	9.750	-2.659	-5.686
.525	147.632	146.591	11.936	9.928	-2.708	-6.047
.537	155.381	156.395	12.282	10.103	-2.755	-6.417
.550	162.890	163.964	12.631	10.273	-2.802	-6.794
.562	169.902	171.036	12.982	10.436	-2.846	-7.179
.575	176.324	177.520	13.334	10.591	-2.868	-7.568
.587	162.013	183.273	13.684	10.737	-2.928	-7.962
.600	186.811	188.135	14.032	10.874	-2.966	-8.358
.612	190.654	192.044	14.376	11.001	-3.000	-8.755
.625	193.522	194.979	14.716	11.117	-3.032	-9.152
.637	195.251	196.774	15.049	11.223	-3.061	-9.547
.650	195.917	197.507	15.375	11.318	-3.087	-9.938
.662	195.550	197.207	15.693	11.402	-3.110	-10.325
.675	193.998	195.720	16.002	11.475	-3.130	-10.704
.687	191.456	193.244	16.301	11.539	-3.147	-11.076
.700	167.977	189.828	16.590	11.593	-3.162	-11.438
.712	183.448	185.361	16.866	11.637	-3.174	-11.789

T (MSEC)	P (PSI)	PPHI	U (FT/SEC)	UX	UY	UZ
.725	178.102	180.076	17.131	11.672	-3.183	-12.128
.737	172.015	174.048	17.384	11.700	-3.191	-12.455
.750	165.169	167.259	17.624	11.720	-3.196	-12.769
.762	157.713	159.856	17.851	11.732	-3.200	-13.068
.775	149.774	151.969	18.065	11.739	-3.202	-13.353
.787	141.445	143.690	18.267	11.741	-3.202	-13.623
.800	132.744	135.035	18.455	11.737	-3.201	-13.877
.812	123.826	126.161	18.630	11.729	-3.199	-14.117
.825	114.811	117.187	18.793	11.718	-3.196	-14.341
.837	105.777	108.191	18.944	11.704	-3.192	-14.550
.850	96.778	99.228	19.083	11.687	-3.187	-14.744
.862	87.878	90.360	19.209	11.669	-3.182	-14.923
.875	79.207	81.719	19.324	11.649	-3.177	-15.087
.887	70.791	73.330	19.428	11.628	-3.171	-15.237
.900	62.678	65.242	19.522	11.606	-3.165	-15.374
.912	54.951	57.537	19.605	11.585	-3.159	-15.498
.925	47.619	50.224	19.679	11.563	-3.153	-15.608
.937	40.708	43.330	19.743	11.541	-3.148	-15.707
.950	34.271	36.909	19.800	11.520	-3.142	-15.795
.962	28.352	31.002	19.849	11.500	-3.136	-15.872
.975	22.917	25.579	19.891	11.480	-3.131	-15.939
.987	17.947	20.618	19.926	11.461	-3.126	-15.997
1.000	13.428	16.106	19.955	11.443	-3.121	-16.047
1.012	9.350	12.034	19.977	11.426	-3.116	-16.088
1.025	5.719	8.406	19.994	11.410	-3.112	-16.122
1.037	2.479	5.171	20.006	11.394	-3.108	-16.148
1.050	-.393	2.301	20.014	11.380	-3.104	-16.169
1.062	-2.921	-.225	20.017	11.366	-3.100	-16.183
1.075	-5.128	-2.433	20.016	11.352	-3.096	-16.193
1.087	-7.038	-4.344	20.012	11.339	-3.093	-16.197
1.100	-8.665	-5.973	20.005	11.327	-3.089	-16.198
1.112	-10.048	-7.359	19.995	11.315	-3.086	-16.194
1.125	-11.215	-8.529	19.983	11.304	-3.083	-16.188
1.137	-12.204	-9.521	19.969	11.293	-3.080	-16.179
1.150	-13.038	-10.360	19.954	11.283	-3.077	-16.167
1.162	-13.733	-11.059	19.937	11.272	-3.074	-16.154
1.175	-14.302	-11.633	19.919	11.262	-3.072	-16.140
1.187	-14.758	-12.094	19.900	11.253	-3.069	-16.124
1.200	-15.113	-12.454	19.881	11.243	-3.066	-16.107
1.212	-15.377	-12.724	19.860	11.233	-3.064	-16.089
1.225	-15.560	-12.912	19.840	11.224	-3.061	-16.071
1.237	-15.670	-13.028	19.819	11.215	-3.059	-16.052
1.250	-15.716	-13.080	19.798	11.206	-3.056	-16.032
1.262	-15.704	-13.073	19.776	11.197	-3.054	-16.013
1.275	-15.640	-13.015	19.755	11.188	-3.051	-15.993
1.287	-15.529	-12.909	19.734	11.179	-3.049	-15.974
1.300	-15.376	-12.762	19.713	11.171	-3.047	-15.954
1.312	-15.184	-12.575	19.692	11.162	-3.044	-15.935

T (MSEC)	P (PSI)	PPHI	U (FT/SEC)	UX	UY	UZ
1.325	-14.958	-12.354	19.672	11.154	-3.042	-15.916
1.337	-14.700	-12.102	19.652	11.145	-3.040	-15.898
1.350	-14.412	-11.820	19.632	11.137	-3.037	-15.880
1.362	-14.094	-11.506	19.613	11.129	-3.035	-15.862
1.375	-13.753	-11.170	19.595	11.121	-3.033	-15.845
1.387	-13.390	-10.812	19.577	11.113	-3.031	-15.829
1.400	-13.009	-10.436	19.559	11.105	-3.029	-15.814
1.412	-12.611	-10.042	19.542	11.097	-3.026	-15.799
1.425	-12.198	-9.634	19.526	11.089	-3.024	-15.784
1.437	-11.773	-9.213	19.510	11.081	-3.022	-15.771
1.450	-11.338	-8.782	19.495	11.073	-3.020	-15.758
1.462	-10.895	-8.342	19.481	11.066	-3.018	-15.746
1.475	-10.446	-7.897	19.467	11.058	-3.016	-15.735
1.487	-9.990	-7.444	19.454	11.050	-3.014	-15.724
1.500	-9.530	-6.988	19.441	11.043	-3.012	-15.715

TOTAL IMPULSE (PSI-MSEC) = 108.6481466

PRESSURE CALCULATED AT POINT

X = 36.00 (IN) Y = 30.00 (IN) Z = 12.00 (IN)

SOURCE COORDINATES

	X	W	X0	Y0	Z0	X1	Y1	Z1	
1	-12.000	5.701	30.500	31.500	.000	30.500	31.500	-60.000	-1.
2	12.000	5.701	30.500	31.500	.000	30.500	31.500	60.000	[illegible]

T (MSEC)	P (PSI)	PPHI	U (FT/SEC)	UX	UY	UZ
.212	.000	.000	.000	.000	.000	.000
.225	.000	.000	.000	.000	.000	.000
.237	157.084	157.125	2.451	1.109	-.303	2.164
.250	167.330	167.382	2.765	1.355	-.370	2.381
.262	177.586	177.651	3.105	1.635	-.446	2.602
.275	187.667	187.748	3.472	1.952	-.532	2.822
.287	197.336	197.436	3.863	2.308	-.629	3.033
.300	206.304	206.427	4.275	2.703	-.737	3.229
.312	214.241	214.390	4.704	3.136	-.855	3.400
.325	220.809	220.987	5.144	3.604	-.983	3.536
.337	225.809	226.020	5.591	4.103	-1.119	3.630
.350	229.457	229.703	6.046	4.629	-1.262	3.678
.362	232.662	232.947	6.518	5.187	-1.415	3.685
.375	236.858	237.190	7.029	5.791	-1.579	3.657
.387	243.819	244.208	7.604	6.461	-1.762	3.600
.400	254.660	255.119	8.263	7.217	-1.968	3.510
.412	269.621	270.167	9.013	8.063	-2.199	3.373
.425	288.424	289.077	9.853	8.999	-2.454	3.177
.437	309.721	310.500	10.767	10.002	-2.728	2.903
.450	332.152	333.078	11.732	11.049	-3.013	2.544
.462	354.533	355.623	12.729	12.112	-3.303	2.099
.475	375.892	377.161	13.739	13.168	-3.591	1.571
.487	395.519	396.982	14.747	14.197	-3.872	.972
.500	412.958	414.625	15.740	15.182	-4.141	.314
.512	427.957	429.834	16.707	16.114	-4.395	-.390
.525	440.418	442.512	17.642	16.985	-4.632	-1.126
.537	450.287	452.598	18.538	17.792	-4.852	-1.880
.550	457.638	460.167	19.391	18.533	-5.054	-2.642
.562	462.575	465.320	20.199	19.209	-5.239	-3.402
.575	465.124	468.079	20.959	19.820	-5.405	-4.149
.587	465.570	468.729	21.672	20.371	-5.556	-4.880
.600	463.817	467.172	22.334	20.863	-5.690	-5.586
.612	460.281	463.824	22.951	21.301	-5.809	-6.265
.625	454.787	458.508	23.518	21.687	-5.915	-6.913
.637	447.778	451.666	24.042	22.026	-6.008	-7.530
.650	439.149	443.193	24.520	22.324	-6.088	-8.112
.662	429.159	433.349	24.958	22.582	-6.159	-8.662
.675	417.973	422.298	25.357	22.804	-6.219	-9.180
.687	405.532	409.981	25.718	22.993	-6.271	-9.666
.700	392.154	396.718	26.046	23.154	-6.315	-10.121
.712	377.942	382.610	26.343	23.289	-6.351	-10.548
.725	362.881	367.645	26.610	23.400	-6.382	-10.948
.737	347.244	352.094	26.852	23.490	-6.406	-11.322
.750	331.167	336.096	27.070	23.563	-6.426	-11.673
.762	314.661	319.662	27.266	23.620	-6.442	-12.002
.775	297.885	302.951	27.443	23.663	-6.454	-12.310
.787	281.003	286.128	27.603	23.694	-6.462	-12.599
.800	264.085	269.264	27.747	23.715	-6.468	-12.871

T (MSEC)	P (PSI)	PPHI	U (FT/SEC)	UX	UY	UZ
.812	247.225	252.452	27.878	23.727	-6.471	-13.126
.825	230.482	235.754	27.995	23.731	-6.472	-13.366
.837	213.982	219.294	28.102	23.729	-6.472	-13.592
.850	197.840	203.189	28.200	23.723	-6.470	-13.806
.862	182.138	187.522	28.290	23.712	-6.467	-14.008
.875	166.913	172.328	28.372	23.698	-6.463	-14.199
.887	152.204	157.648	28.448	23.682	-6.459	-14.380
.900	138.042	143.513	28.519	23.663	-6.454	-14.550
.912	124.456	129.951	28.583	23.643	-6.448	-14.711
.925	111.488	117.006	28.643	23.622	-6.442	-14.863
.937	99.141	104.681	28.697	23.600	-6.436	-15.005
.950	87.429	92.988	28.748	23.578	-6.430	-15.138
.962	76.383	81.960	28.793	23.556	-6.424	-15.262
.975	66.002	71.595	28.835	23.533	-6.418	-15.377
.987	56.274	61.882	28.873	23.511	-6.412	-15.484
1.000	47.198	52.819	28.906	23.489	-6.406	-15.582
1.012	38.809	44.441	28.936	23.468	-6.400	-15.672
1.025	31.054	36.697	28.963	23.447	-6.395	-15.754
1.037	23.920	29.572	28.986	23.427	-6.389	-15.828
1.050	17.389	23.049	29.006	23.407	-6.384	-15.895
1.062	11.483	17.149	29.022	23.389	-6.379	-15.955
1.075	6.135	11.806	29.036	23.371	-6.374	-16.008
1.087	1.322	6.997	29.047	23.354	-6.369	-16.054
1.100	-2.984	2.694	29.055	23.337	-6.365	-16.094
1.112	-6.800	-1.119	29.060	23.322	-6.360	-16.129
1.125	-10.146	-4.464	29.064	23.307	-6.356	-16.158
1.137	-13.072	-7.390	29.065	23.293	-6.353	-16.182
1.150	-15.608	-9.926	29.064	23.279	-6.349	-16.202
1.162	-17.782	-12.101	29.062	23.266	-6.345	-16.218
1.175	-19.621	-13.942	29.058	23.253	-6.342	-16.230
1.187	-21.150	-15.473	29.052	23.241	-6.339	-16.239
1.200	-22.389	-16.714	29.045	23.230	-6.335	-16.244
1.212	-23.373	-17.701	29.038	23.219	-6.332	-16.248
1.225	-24.125	-18.457	29.029	23.208	-6.329	-16.249
1.237	-24.685	-19.020	29.020	23.198	-6.327	-16.248
1.250	-25.076	-19.415	29.011	23.188	-6.324	-16.247
1.262	-25.316	-19.658	29.001	23.178	-6.321	-16.244
1.275	-25.417	-19.764	28.991	23.168	-6.319	-16.241
1.287	-25.395	-19.745	28.980	23.159	-6.316	-16.236
1.300	-25.261	-19.616	28.970	23.150	-6.314	-16.232
1.312	-25.028	-19.386	28.960	23.141	-6.311	-16.227
1.325	-24.705	-19.068	28.949	23.133	-6.309	-16.222
1.337	-24.304	-18.670	28.939	23.124	-6.307	-16.217
1.350	-23.833	-18.204	28.929	23.116	-6.304	-16.211
1.362	-23.300	-17.675	28.919	23.108	-6.302	-16.207
1.375	-22.708	-17.086	28.910	23.100	-6.300	-16.202
1.387	-22.070	-16.452	28.901	23.092	-6.298	-16.198
1.400	-21.395	-15.780	28.892	23.084	-6.296	-16.194

TIMSEC	P (PSI)	PPHI	U (FT/SEC)	UX	UY	UZ
1.412	-20.689	-15.077	28.883	23.076	-6.293	-16.190
1.425	-19.957	-14.349	28.874	23.068	-6.291	-16.187
1.437	-19.206	-13.601	28.866	23.061	-6.289	-16.184
1.450	-18.442	-12.840	28.858	23.053	-6.287	-16.181
1.462	-17.670	-12.071	28.850	23.045	-6.285	-16.179
1.475	-16.893	-11.297	28.843	23.038	-6.283	-16.177
1.487	-16.113	-10.520	28.836	23.030	-6.281	-16.176
1.500	-15.338	-9.747	28.829	23.022	-6.279	-16.175

TOTAL IMPULSE (PSI-MSEC) = 212.7828846

PRESSURE CALCULATED AT POINT

X = 36.00 (IN)   Y = 30.00 (IN)   Z = 18.00 (IN)

SOURCE COORDINATES

	X	W	X0	Y0	Z0	X1	Y1	Z1	
1	-18.000	5.701	30.500	31.500	.000	30.500	31.500	-60.000	-1.
2	18.000	5.701	30.500	31.500	.000	30.500	31.500	60.000	1.

T (MSEC)	P (PSI)	PPHI	U (FT/SEC)	UX	UY	UZ
.300	.000	.000	.000	.000	.000	.000
.312	.000	.000	.000	.000	.000	.000
.325	116.488	116.510	1.797	.538	-.147	1.708
.337	123.179	123.205	1.974	.632	-.172	1.862
.350	130.220	130.252	2.167	.737	-.201	2.028
.362	137.623	137.661	2.376	.857	-.234	2.204
.375	145.391	145.436	2.604	.994	-.271	2.392
.387	153.517	153.572	2.851	1.148	-.313	2.590
.400	161.978	162.044	3.118	1.325	-.361	2.800
.412	170.757	170.835	3.408	1.525	-.416	3.019
.425	180.090	180.183	3.725	1.756	-.479	3.251
.437	191.230	191.343	4.092	2.030	-.554	3.510
.450	207.342	207.482	4.562	2.381	-.649	3.836
.462	233.527	233.710	5.222	2.868	-.782	4.293
.475	274.958	275.214	6.169	3.569	-.973	4.937
.487	334.005	334.380	7.465	4.553	-1.242	5.784
.500	409.284	409.843	9.118	5.866	-1.600	6.795
.512	495.191	496.016	11.072	7.510	-2.048	7.874
.525	584.979	586.159	13.246	9.453	-2.578	8.914
.537	671.379	673.003	15.541	11.631	-3.172	9.807
.550	748.292	750.438	17.861	13.960	-3.807	10.472
.562	811.272	813.996	20.125	16.347	-4.458	10.859
.575	858.027	861.363	22.272	18.707	-5.102	10.957
.587	888.338	892.299	24.266	20.972	-5.720	10.784
.600	903.043	907.619	26.083	23.086	-6.296	10.377
.612	903.993	909.161	27.717	25.018	-6.823	9.787
.625	893.677	899.402	29.175	26.754	-7.297	9.062
.637	874.435	880.679	30.465	28.294	-7.716	8.249
.650	848.480	855.198	31.662	29.644	-8.085	7.389
.662	817.621	824.770	32.599	30.816	-8.404	6.513
.675	783.489	791.025	33.471	31.829	-8.681	5.646
.687	747.489	755.372	34.233	32.700	-8.918	4.802
.700	710.471	718.662	34.896	33.445	-9.121	3.996
.712	673.246	681.711	35.474	34.081	-9.295	3.234
.725	636.346	645.053	35.976	34.623	-9.443	2.519
.737	600.191	609.110	36.412	35.084	-9.568	1.852
.750	564.974	574.080	36.791	35.475	-9.675	1.233
.762	530.934	540.203	37.120	35.806	-9.765	.660
.775	498.241	507.653	37.436	36.088	-9.842	.130
.787	466.985	476.524	37.656	36.328	-9.908	-.362
.800	437.155	446.804	37.876	36.532	-9.963	-.818
.812	408.704	418.452	38.067	36.706	-10.011	-1.242
.825	381.554	391.388	38.235	36.854	-10.051	-1.636
.837	355.661	365.571	38.383	36.980	-10.085	-2.004
.850	330.967	340.944	38.511	37.085	-10.114	-2.347
.862	307.383	317.418	38.624	37.174	-10.138	-2.669
.875	284.879	294.965	38.723	37.248	-10.159	-2.971
.887	263.416	273.548	38.809	37.310	-10.175	-3.255
.900	242.935	253.106	38.885	37.360	-10.189	-3.522

T (MSEC)	P (PSI)	PPHI	U (FT/SEC)	UX	UY	UZ
.912	223.413	233.616	38.951	37.402	-10.200	-3.774
.925	204.810	215.046	39.009	37.435	-10.210	-4.012
.937	187.083	197.346	39.060	37.461	-10.217	-4.237
.950	170.209	180.495	39.105	37.482	-10.222	-4.450
.962	154.170	164.476	39.144	37.497	-10.226	-4.652
.975	138.940	149.265	39.178	37.508	-10.229	-4.843
.987	124.503	134.844	39.208	37.515	-10.231	-5.024
1.000	110.843	121.198	39.234	37.519	-10.232	-5.195
1.012	97.943	108.310	39.258	37.520	-10.233	-5.357
1.025	85.803	96.181	39.278	37.519	-10.232	-5.510
1.037	74.397	84.784	39.296	37.517	-10.232	-5.654
1.050	63.710	74.105	39.311	37.512	-10.231	-5.790
1.062	53.747	64.149	39.325	37.507	-10.229	-5.917
1.075	44.488	54.897	39.337	37.501	-10.228	-6.037
1.087	35.907	46.322	39.348	37.495	-10.226	-6.148
1.100	27.989	38.408	39.357	37.488	-10.224	-6.253
1.112	20.750	31.174	39.365	37.481	-10.222	-6.349
1.125	14.139	24.566	39.372	37.473	-10.220	-6.439
1.137	8.133	18.564	39.378	37.466	-10.218	-6.522
1.150	2.712	13.145	39.384	37.459	-10.216	-6.598
1.162	-2.119	8.317	39.388	37.452	-10.214	-6.668
1.175	-6.413	4.026	39.392	37.445	-10.212	-6.733
1.187	-10.199	.241	39.396	37.439	-10.211	-6.791
1.200	-13.497	-3.055	39.399	37.433	-10.209	-6.845
1.212	-16.337	-5.893	39.402	37.427	-10.207	-6.895
1.225	-18.734	-8.289	39.405	37.422	-10.206	-6.939
1.237	-20.741	-10.295	39.407	37.417	-10.205	-6.980
1.250	-22.385	-11.938	39.409	37.413	-10.203	-7.017
1.262	-23.697	-13.149	39.410	37.408	-10.202	-7.050
1.275	-24.703	-14.255	39.412	37.404	-10.201	-7.081
1.287	-25.432	-14.983	39.413	37.401	-10.200	-7.108
1.300	-25.902	-15.452	39.414	37.397	-10.199	-7.134
1.312	-26.148	-15.698	39.415	37.394	-10.198	-7.157
1.325	-26.200	-15.750	39.416	37.391	-10.198	-7.178
1.337	-26.092	-15.641	39.416	37.388	-10.197	-7.198
1.350	-25.839	-15.388	39.417	37.385	-10.196	-7.217
1.362	-25.471	-15.019	39.417	37.382	-10.195	-7.234
1.375	-25.003	-14.551	39.417	37.379	-10.194	-7.251
1.387	-24.450	-13.999	39.417	37.377	-10.194	-7.267
1.400	-23.828	-13.376	39.417	37.374	-10.193	-7.282
1.412	-23.148	-12.697	39.417	37.371	-10.192	-7.296
1.425	-22.423	-11.972	39.416	37.367	-10.191	-7.310
1.437	-21.663	-11.213	39.415	37.364	-10.190	-7.324
1.450	-20.878	-10.429	39.414	37.361	-10.189	-7.337
1.462	-20.073	-9.624	39.413	37.357	-10.188	-7.349
1.475	-19.259	-8.811	39.411	37.353	-10.187	-7.361
1.487	-18.444	-7.997	39.409	37.349	-10.186	-7.373
1.500	-17.633	-7.186	39.407	37.345	-10.185	-7.385

TOTAL IMPULSE (PSI-MSEC) = 297.1140862

PRESSURE CALCULATED AT POINT

X = 36.00 (IN) Y = 30.00 (IN) Z = 24.00 (IN)

SOURCE COORDINATES

	X	W	X0	Y0	Z0	X1	Y1	Z1	
1	-24.000	5.701	30.500	31.500	.000	30.500	31.500	-60.000	-1.
2	24.000	5.701	30.500	31.500	.000	30.500	31.500	60.000	1.

T (MSEC)	P (PSI)	PPHI	U (FT/SEC)	UX	UY	UZ
.400	.000	.000	.000	.000	.000	.000
.412	.000	.000	.000	.000	.000	.000
.425	92.821	92.835	1.426	.328	-.089	1.385
.437	97.086	97.102	1.536	.372	-.101	1.487
.450	101.580	101.599	1.654	.421	-.115	1.596
.462	106.321	106.342	1.782	.476	-.130	1.712
.475	111.326	111.351	1.919	.538	-.147	1.836
.487	116.615	116.643	2.067	.606	-.165	1.969
.500	122.206	122.239	2.227	.683	-.186	2.111
.512	128.191	128.230	2.400	.769	-.210	2.264
.525	135.192	135.238	2.598	.870	-.237	2.436
.537	145.439	145.494	2.856	.999	-.272	2.661
.550	163.497	163.568	3.248	1.186	-.323	3.006
.562	195.562	195.663	3.878	1.478	-.403	3.562
.575	246.768	246.925	4.839	1.928	-.526	4.407
.587	317.923	318.178	6.163	2.573	-.702	5.556
.600	405.709	406.120	7.824	3.431	-.936	6.969
.612	503.819	504.458	9.747	4.497	-1.227	8.560
.625	604.292	605.233	11.829	5.747	-1.567	10.219
.637	698.836	700.146	13.955	7.137	-1.947	11.832
.650	780.509	782.236	16.021	8.616	-2.350	13.301
.662	844.799	846.967	17.953	10.134	-2.764	14.560
.675	889.906	892.520	19.711	11.648	-3.177	15.581
.687	916.163	919.209	21.281	13.128	-3.580	16.362
.700	925.642	929.100	22.673	14.557	-3.970	16.924
.712	921.298	925.144	23.911	15.928	-4.344	17.297
.725	905.795	910.004	25.015	17.233	-4.700	17.512
.737	882.114	886.664	26.009	18.478	-5.039	17.597
.750	852.231	857.101	26.907	19.656	-5.361	17.576
.762	818.238	823.410	27.727	20.772	-5.665	17.470
.775	781.732	787.187	28.478	21.827	-5.953	17.295
.787	744.189	749.914	29.174	22.826	-6.225	17.068
.800	706.326	712.307	29.818	23.768	-6.482	16.798
.812	668.679	674.901	30.413	24.652	-6.723	16.495
.825	631.564	638.011	30.959	25.475	-6.948	16.163
.837	595.262	601.919	31.458	26.238	-7.156	15.809
.850	560.042	566.892	31.912	26.943	-7.348	15.442
.862	525.922	532.949	32.321	27.588	-7.524	15.065
.875	493.135	500.324	32.690	28.178	-7.685	14.683
.887	461.619	468.953	33.019	28.714	-7.831	14.300
.900	431.377	438.841	33.311	29.198	-7.963	13.918
.912	402.608	410.189	33.571	29.636	-8.082	13.543
.925	375.096	382.780	33.799	30.029	-8.190	13.175
.937	348.854	356.629	33.998	30.381	-8.286	12.815
.950	323.897	331.752	34.171	30.695	-8.371	12.466
.962	300.230	308.154	34.322	30.977	-8.448	12.128
.975	277.741	285.726	34.453	31.227	-8.517	11.802
.987	256.409	264.445	34.564	31.450	-8.577	11.489

T (MSEC)	P (PSI)	PPHI	U (FT/SEC)	UX	UY	UZ
1.000	236.181	244.262	34.660	31.649	-8.631	11.187
1.012	217.028	225.146	34.740	31.825	-8.679	10.898
1.025	198.923	207.073	34.809	31.981	-8.722	10.620
1.037	181.821	189.999	34.867	32.120	-8.760	10.355
1.050	165.696	173.897	34.915	32.245	-8.794	10.101
1.062	150.529	158.749	34.956	32.356	-8.824	9.858
1.075	136.266	144.501	34.990	32.455	-8.851	9.626
1.087	122.879	131.128	35.019	32.544	-8.876	9.404
1.100	110.342	118.602	35.042	32.624	-8.897	9.192
1.112	98.625	106.894	35.062	32.696	-8.917	8.990
1.125	87.715	95.992	35.078	32.761	-8.935	8.797
1.137	77.577	85.861	35.092	32.820	-8.951	8.612
1.150	68.184	76.473	35.104	32.874	-8.966	8.437
1.162	59.521	67.815	35.114	32.924	-8.979	8.270
1.175	51.566	59.865	35.123	32.969	-8.992	8.111
1.187	44.281	52.583	35.131	33.012	-9.003	7.960
1.200	37.637	45.942	35.138	33.051	-9.014	7.816
1.212	31.630	39.939	35.145	33.087	-9.024	7.680
1.225	26.224	34.536	35.152	33.122	-9.033	7.551
1.237	21.377	29.692	35.159	33.154	-9.042	7.429
1.250	17.056	25.374	35.165	33.184	-9.050	7.313
1.262	13.249	21.570	35.172	33.213	-9.058	7.204
1.275	9.914	18.239	35.178	33.240	-9.065	7.101
1.287	7.011	15.339	35.185	33.266	-9.072	7.004
1.300	4.508	12.838	35.191	33.290	-9.079	6.912
1.312	2.373	10.707	35.198	33.313	-9.085	6.825
1.325	.593	8.930	35.204	33.334	-9.091	6.744
1.337	-.877	7.462	35.210	33.355	-9.097	6.668
1.350	-2.071	6.272	35.216	33.374	-9.102	6.596
1.362	-3.015	5.330	35.222	33.392	-9.107	6.528
1.375	-3.737	4.611	35.228	33.410	-9.112	6.465
1.387	-4.259	4.091	35.233	33.426	-9.116	6.405
1.400	-4.601	3.752	35.239	33.441	-9.120	6.348
1.412	-4.788	3.567	35.243	33.455	-9.124	6.295
1.425	-4.848	3.509	35.248	33.468	-9.128	6.245
1.437	-4.810	3.550	35.252	33.480	-9.131	6.197
1.450	-4.692	3.669	35.255	33.491	-9.134	6.152
1.462	-4.508	3.854	35.258	33.501	-9.137	6.109
1.475	-4.269	4.094	35.260	33.511	-9.139	6.068
1.487	-3.987	4.378	35.262	33.519	-9.142	6.029
1.500	-3.668	4.696	35.264	33.527	-9.144	5.991

TOTAL IMPULSE (PSI-MSEC) = 300.5120926

PRESSURE CALCULATED AT POINT

X = 36.00 (IN) Y = 30.00 (IN) Z = 30.00 (IN)

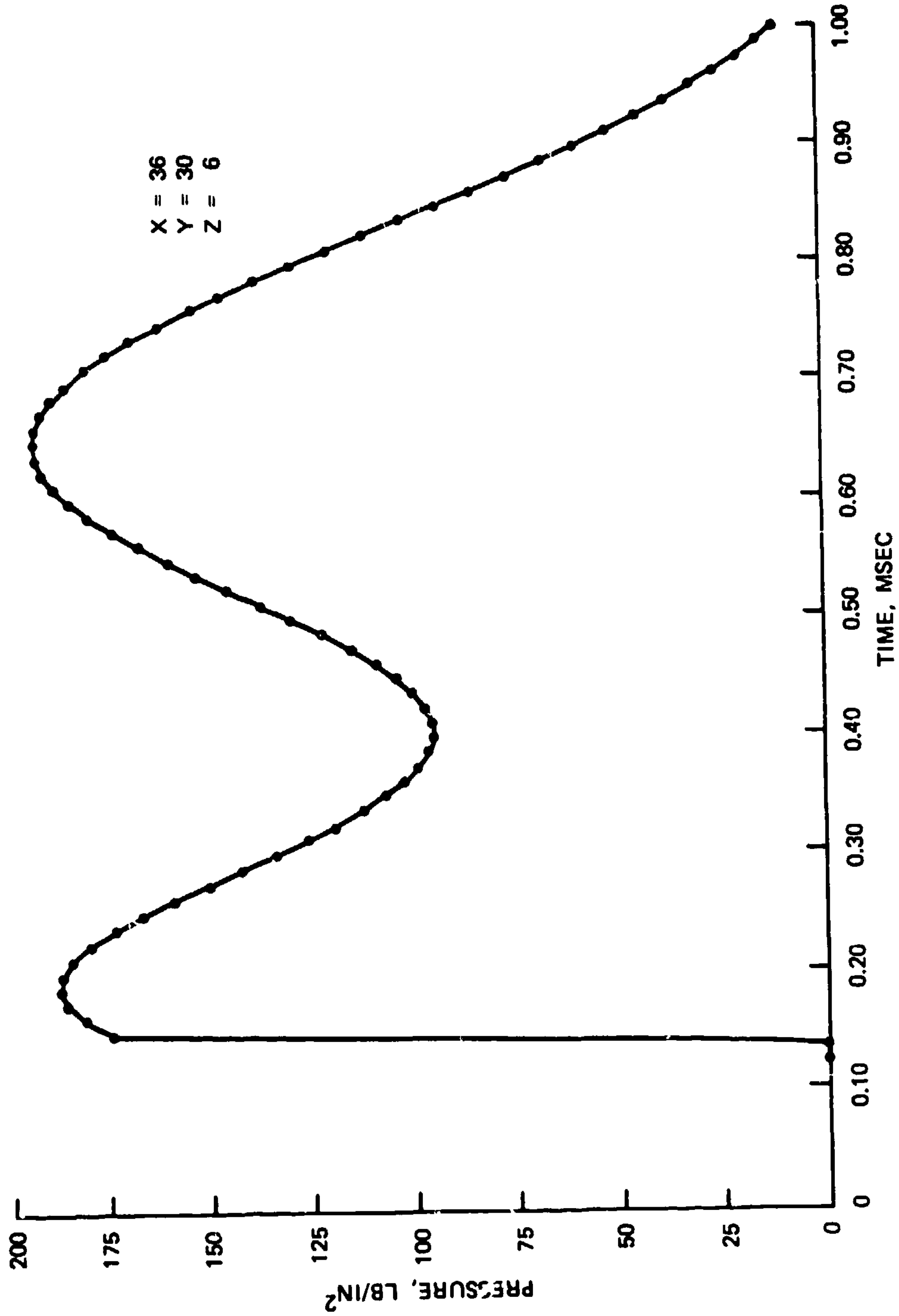
SOURCE COORDINATES

	X	W	X0	Y0	Z0	X1	Y1	Z1	
1	-30.000	5.701	30.500	31.500	.000	30.500	31.500	-60.000	-1.
2	30.000	5.701	30.500	31.500	.000	30.500	31.500	60.000	1.

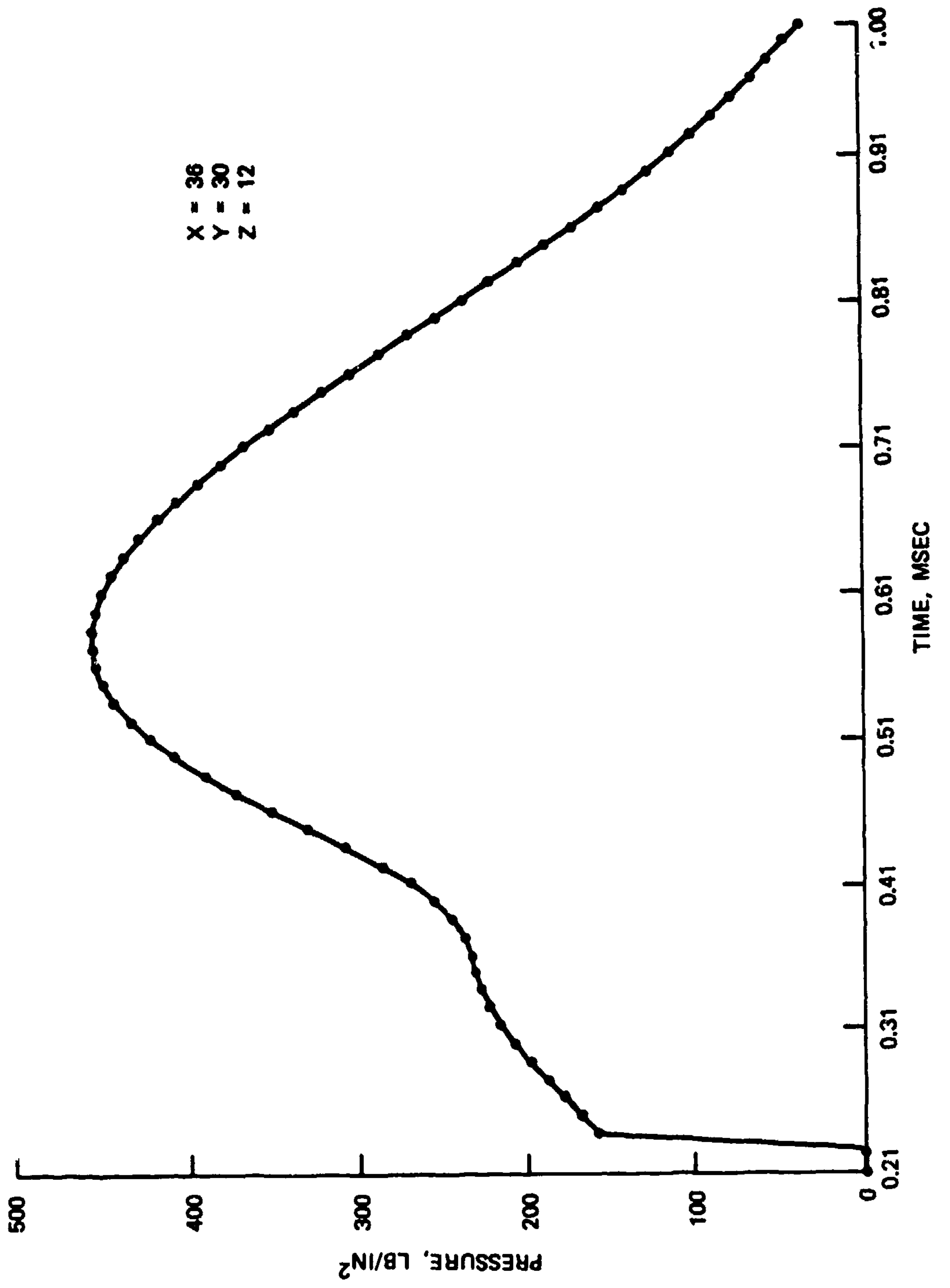
T (MSEC)	P (PSI)	PPHI	U (FT/SEC)	UX	UY	UZ
.500	.000	.000	.000	.000	.000	.000
.512	.000	.000	.000	.000	.000	.000
.525	76.128	76.137	1.166	.216	-.059	1.144
.537	78.944	78.954	1.238	.239	-.065	1.213
.550	81.896	81.908	1.315	.265	-.072	1.286
.562	84.994	85.008	1.397	.293	-.080	1.364
.575	88.250	88.265	1.485	.324	-.088	1.446
.587	91.676	91.692	1.578	.358	-.098	1.533
.600	95.286	95.305	1.677	.395	-.108	1.626
.612	99.189	99.210	1.785	.437	-.119	1.726
.625	104.069	104.093	1.912	.486	-.132	1.844
.637	112.172	112.202	2.093	.551	-.150	2.014
.650	127.751	127.790	2.397	.653	-.178	2.299
.662	156.203	156.260	2.910	.820	-.224	2.784
.675	200.708	200.800	3.692	1.076	-.293	3.519
.687	260.814	260.965	4.746	1.434	-.391	4.507
.700	332.608	332.852	6.025	1.892	-.516	5.697
.712	409.727	410.100	7.442	2.432	-.663	7.002
.725	484.861	485.393	8.894	3.029	-.826	8.321
.737	551.091	551.801	10.276	3.647	-.995	9.555
.750	603.449	604.340	11.510	4.255	-1.160	10.632
.762	639.628	640.689	12.555	4.829	-1.317	11.514
.775	659.736	660.944	13.401	5.355	-1.460	12.197
.787	665.930	667.262	14.071	5.830	-1.590	12.707
.800	661.122	662.556	14.600	6.261	-1.708	13.079
.812	648.238	649.756	15.024	6.656	-1.815	13.347
.825	629.893	631.483	15.375	7.023	-1.915	13.542
.837	607.980	609.633	15.676	7.370	-2.010	13.689
.850	584.534	586.246	15.954	7.708	-2.102	13.809
.862	560.832	562.603	16.226	8.045	-2.194	13.919
.875	537.434	539.265	16.498	8.385	-2.287	14.023
.887	514.633	516.526	16.773	8.729	-2.381	14.124
.900	492.602	494.559	17.054	9.079	-2.476	14.223
.912	471.414	473.436	17.340	9.436	-2.574	14.319
.925	451.082	453.173	17.632	9.801	-2.673	14.411
.937	431.578	433.740	17.926	10.172	-2.774	14.498
.950	412.825	415.059	18.223	10.550	-2.877	14.578
.962	394.750	397.057	18.520	10.933	-2.982	14.648
.975	377.403	379.784	18.817	11.322	-3.088	14.709
.987	360.590	363.047	19.111	11.714	-3.195	14.753
1.000	344.250	346.782	19.399	12.109	-3.303	14.792
1.012	328.497	331.103	19.684	12.507	-3.411	14.812
1.025	313.085	315.765	19.960	12.904	-3.519	14.816
1.037	298.188	300.941	20.229	13.300	-3.627	14.804
1.050	283.612	286.435	20.488	13.694	-3.735	14.775
1.062	269.556	272.449	20.739	14.085	-3.841	14.730
1.075	255.816	258.777	20.979	14.471	-3.947	14.667
1.087	242.551	245.577	21.208	14.851	-4.053	14.589

T (MSEC)	P (PSI)	PPHI	U (FT/SEC)	UX	UY	UZ
1.100	229.719	232.807	21.427	15.224	-4.152	14.496
1.112	217.263	220.411	21.634	15.588	-4.251	14.387
1.125	205.309	208.515	21.831	15.945	-4.349	14.264
1.137	193.824	197.085	22.018	16.291	-4.443	14.129
1.150	182.759	186.072	22.193	16.627	-4.535	13.982
1.162	172.137	175.499	22.357	16.951	-4.623	13.825
1.175	162.013	165.421	22.511	17.263	-4.708	13.659
1.187	152.364	155.817	22.656	17.564	-4.790	13.485
1.200	143.156	146.650	22.791	17.852	-4.869	13.305
1.212	134.385	137.918	22.916	18.127	-4.944	13.119
1.225	126.058	129.626	23.032	18.399	-5.015	12.930
1.237	118.166	121.768	23.141	18.639	-5.083	12.738
1.250	110.699	114.333	23.241	18.875	-5.148	12.545
1.262	103.655	107.317	23.334	19.099	-5.209	12.352
1.275	97.048	100.738	23.420	19.311	-5.267	12.159
1.287	90.836	94.550	23.499	19.510	-5.321	11.969
1.300	85.009	88.747	23.573	19.698	-5.372	11.782
1.312	79.569	83.329	23.641	19.875	-5.420	11.598
1.325	74.511	78.291	23.704	20.040	-5.466	11.418
1.337	69.808	73.606	23.762	20.196	-5.508	11.243
1.350	65.447	69.262	23.815	20.341	-5.548	11.073
1.362	61.423	65.254	23.864	20.477	-5.585	10.909
1.375	57.733	61.579	23.910	20.605	-5.619	10.750
1.387	54.345	58.204	23.952	20.724	-5.652	10.597
1.400	51.243	55.115	23.991	20.835	-5.682	10.450
1.412	48.413	52.296	24.027	20.938	-5.710	10.310
1.425	45.843	49.737	24.061	21.035	-5.737	10.175
1.437	43.524	47.428	24.091	21.125	-5.761	10.046
1.450	41.427	45.341	24.120	21.210	-5.784	9.923
1.462	39.536	43.458	24.146	21.288	-5.806	9.805
1.475	37.836	41.765	24.170	21.361	-5.826	9.692
1.487	36.310	40.246	24.192	21.429	-5.844	9.585
1.500	34.944	38.887	24.212	21.493	-5.862	9.483

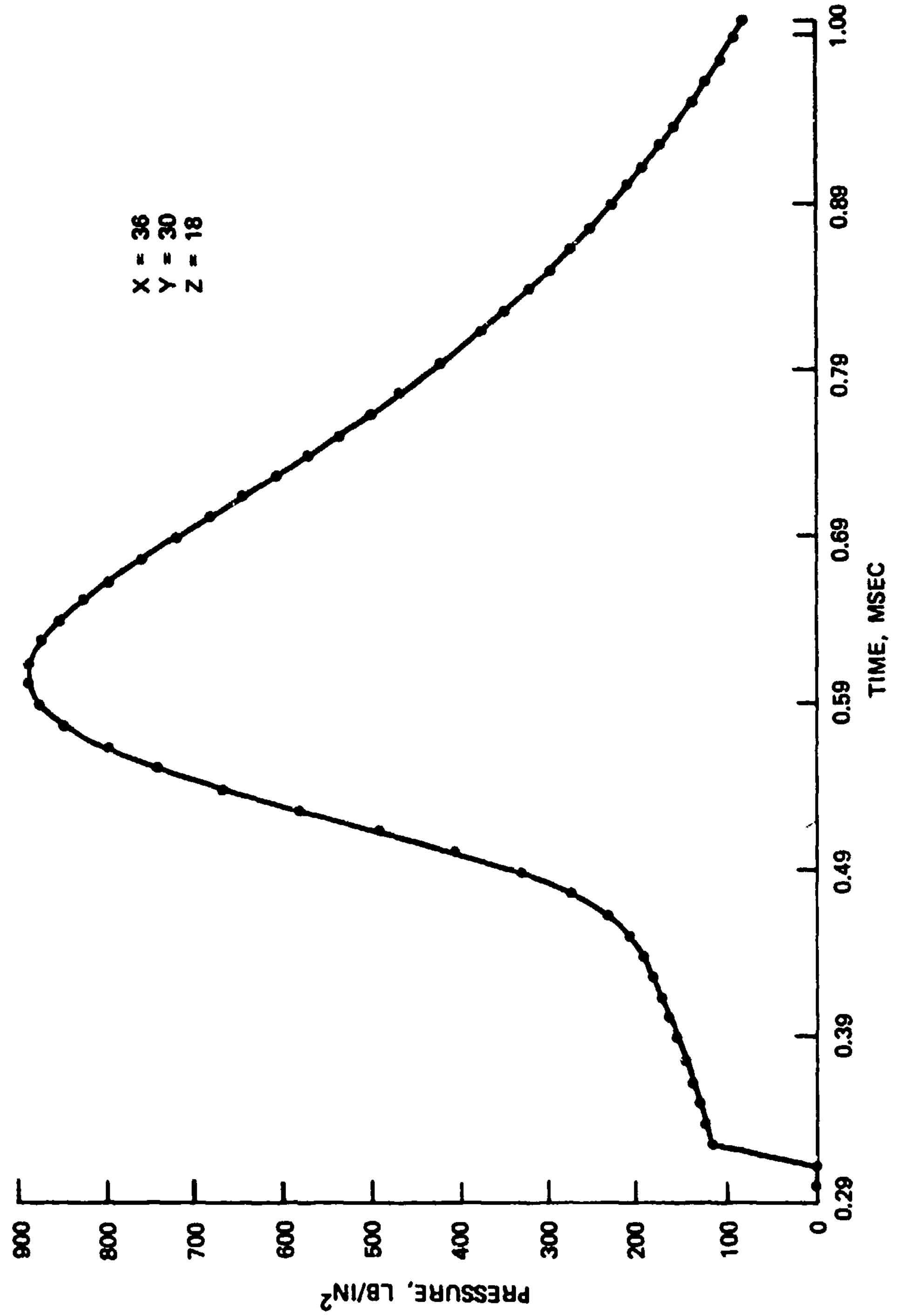
TOTAL IMPULSE (PSI-MSEC) = 247.8301487



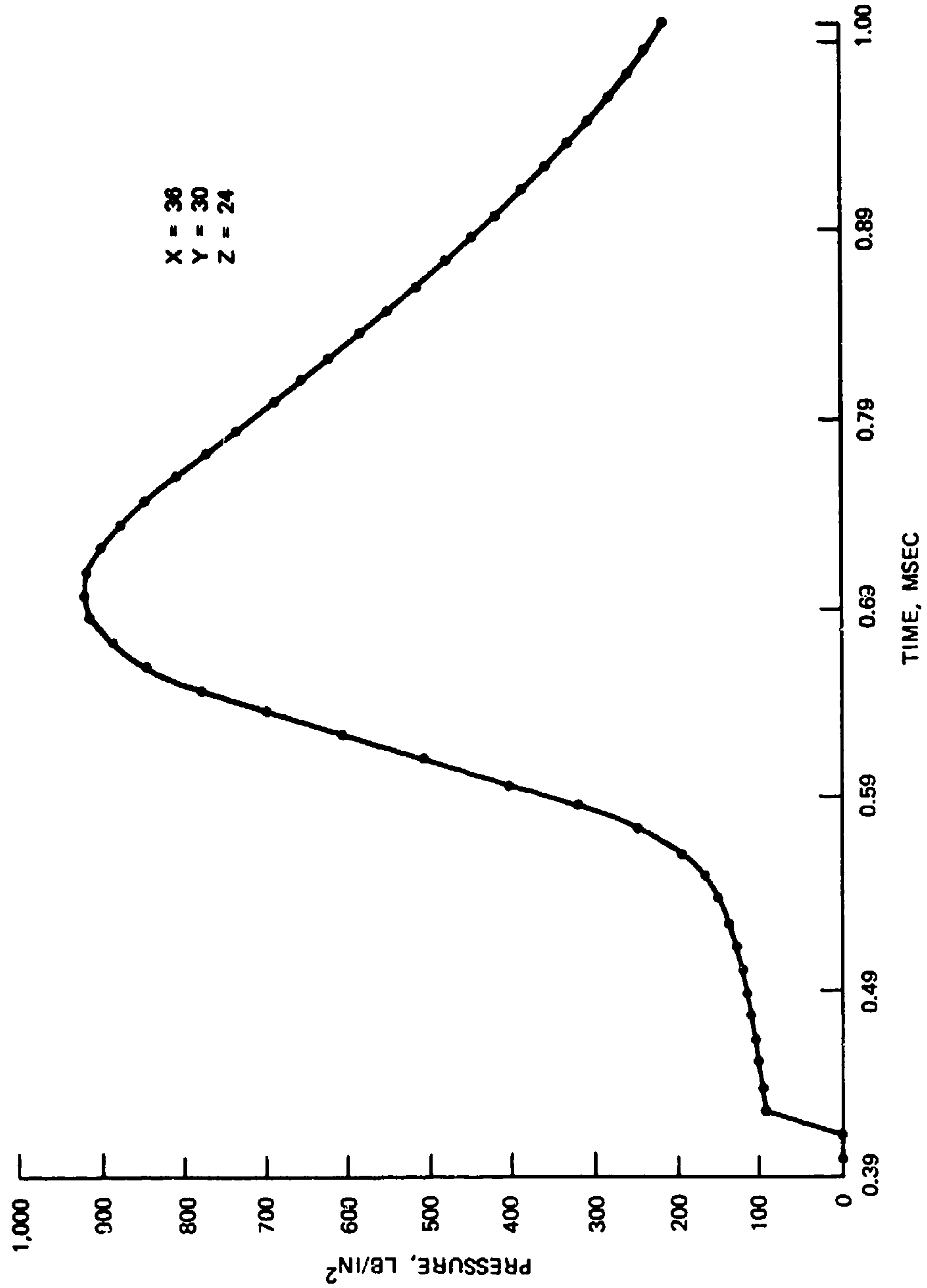
PRESSURE VERSUS TIME PLOT FOR RUN 1HR1 XDUCR 1



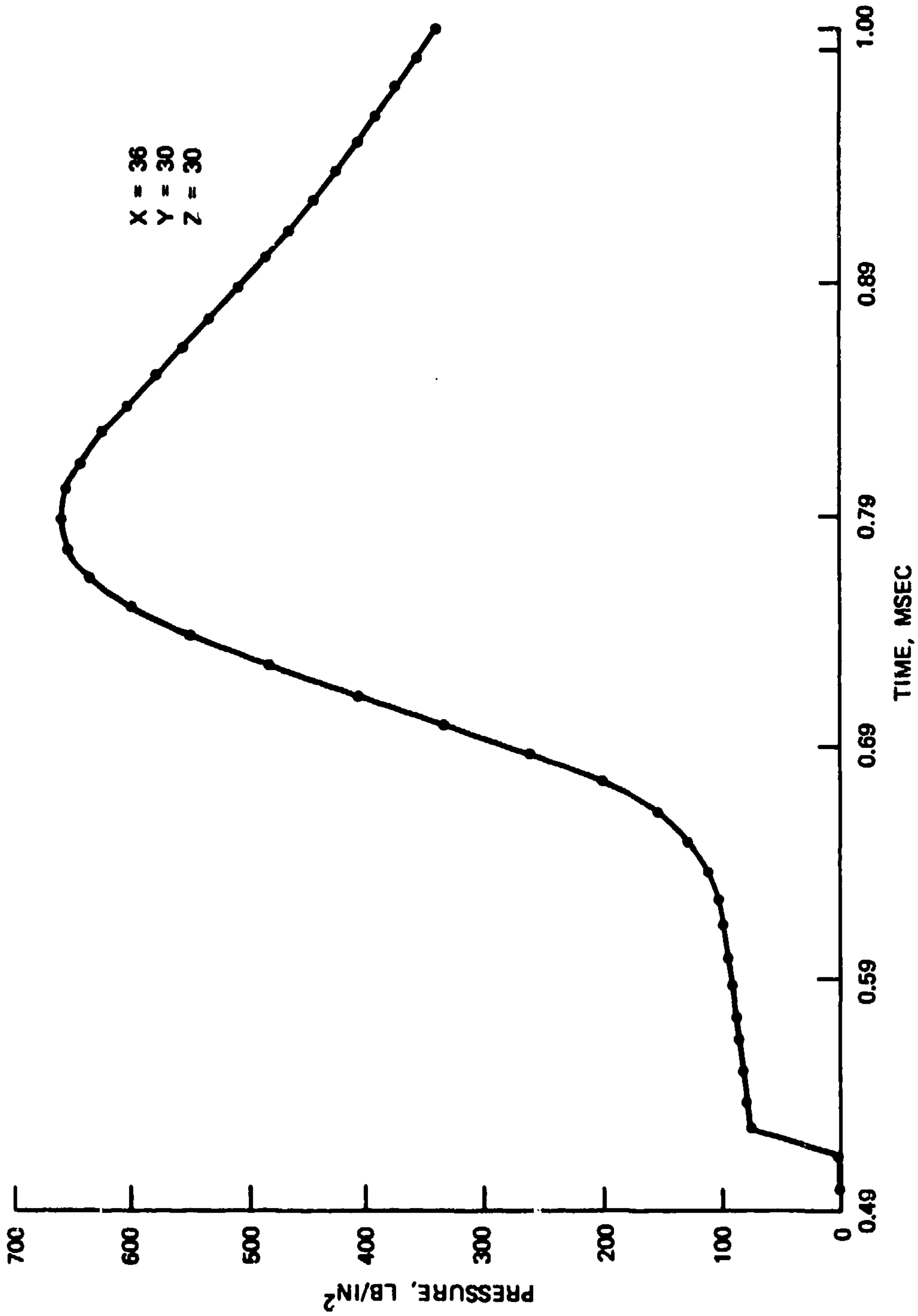
PRESSURE VERSUS TIME PLOT FOR RUN 1HR1 XDUCR 2



PRESSURE VERSUS TIME PLOT FOR RUN 1HR1 XDUCR 3



PRESSURE VERSUS TIME PLOT FOR RUN 1HR1 XDUCR 4



PRESSURE VERSUS TIME PLOT FOR RUN 1HR1 XDUCR 5

Appendix A

DERIVATIVES OF POTENTIAL

POTENTIAL

$$\phi = -\frac{B}{2} \int_{o}^{X_b(\tau)} \frac{1}{r} \left\{ A(\xi) - B\left[t - \frac{r}{c} - t_b(\xi)\right]\right\} d\xi$$

LEIBNITZ'S RULE

$$\frac{\partial\phi}{\partial t} = -\frac{BA_b}{2R_b}\left[\frac{\partial X_b(\tau)}{\partial t}\right] + \frac{B^2}{2}\int_{o}^{X_b(\tau)} \frac{d\xi}{r}$$

$$\frac{\partial\phi}{\partial\omega} = -\frac{BA_b}{2R_b}\left[\frac{\partial X_b(\tau)}{\partial\omega}\right] - \frac{B}{2}\int_{o}^{X_b(\tau)} \frac{\partial 1/r}{\partial\omega}\left\{A(\xi) - B\left[t - t_b(\xi)\right]\right\} d\xi$$

$$\frac{\partial\phi}{\partial x} = -\frac{BA_b}{2R_b}\left[\frac{\partial X_b(\tau)}{\partial x}\right] - \frac{B}{2}\int_{o}^{X_b(\tau)} \frac{\partial 1/r}{\partial x}\left\{A(\xi) - B\left[t - t_b(\xi)\right]\right\} d\xi$$

DERIVATIVES OF $X_b(\tau)$

$$\frac{\partial X_b(\tau)}{\partial t} = \frac{\partial X_b(\tau)}{\partial\tau}\frac{\partial\tau}{\partial t} = V\frac{\partial\tau}{\partial t}$$

Similarly,

$$\frac{\partial X_b(\tau)}{\partial\omega} = V\frac{\partial\tau}{\partial\omega}$$

$$\frac{\partial X_b(\tau)}{\partial x} = V\frac{\partial\tau}{\partial x}$$

Since $\tau = t - \frac{R_b}{c}$; $R_b = \sqrt{\omega^2 + (x - X_b)^2}$

$$\frac{\partial \tau}{\partial t} = 1 - \frac{1}{c}\frac{\partial R_b}{\partial t} = 1 + \frac{1}{c}\frac{x - X_b}{R_b}\frac{\partial X_b(\tau)}{\partial t}$$

$$\therefore \frac{\partial X_b(\tau)}{\partial t} = V\left[1 + \frac{1}{c}\frac{x - X_b}{R_b}\frac{\partial X_b(\tau)}{\partial t}\right]$$

$$\star \therefore \frac{\partial X_b(\tau)}{\partial t} = \frac{V}{1 - \frac{V}{c}\frac{x - X_b}{R_b}}$$

$$\frac{\partial \tau}{\partial \omega} = -\frac{1}{c}\frac{\partial R_b}{\partial \omega} = -\frac{1}{cR_b}\left[\omega - (x - X_b)\frac{\partial X_b(\tau)}{\partial \omega}\right]$$

$$\therefore \frac{\partial X_b(\tau)}{\partial \omega} = -\frac{V}{cR_b}\left[\omega - (x - X_b)\frac{\partial X_b(\tau)}{\partial \omega}\right]$$

$$\star \therefore \frac{\partial X_b(\tau)}{\partial \omega} = \frac{-\frac{V}{c}\frac{\omega}{R_b}}{1 - \frac{V}{c}\frac{x - X_b}{R_b}}$$

$$\frac{\partial \tau}{\partial x} = -\frac{1}{c}\frac{\partial R_b}{\partial x} = -\frac{1}{cR_b}(x - X_b)\left[1 - \frac{\partial X_b(\tau)}{\partial x}\right]$$

$$\therefore \frac{\partial X_b(\tau)}{\partial x} = -\frac{V}{c}\frac{x - X_b}{R_b}\left[1 - \frac{\partial X_b(\tau)}{\partial x}\right]$$

$$\star \therefore \frac{\partial X_b(\tau)}{\partial x} = \frac{-\frac{V}{c}\frac{x - X_b}{R_b}}{1 - \frac{V}{c}\frac{x - X_b}{R_b}}$$

Integral in $\partial\phi/\partial t$ expression

$$I \equiv \int_0^{X_b} \frac{d\xi}{r} = \int_0^{X_b} \frac{d\xi}{\sqrt{\omega^2 + (x - \xi)^2}}$$

$$y \equiv x - \xi \qquad \xi = x - y \qquad d\xi = -dy$$

$$I = -\int_x^{x - X_b} \frac{dy}{\sqrt{\omega^2 + y^2}}$$

From tables

$$I = -\left[\ln\left(y + \sqrt{\omega^2 + y^2}\right)\right]_x^{x - X_b}$$

$$= \ln \frac{x + \sqrt{\omega^2 + x^2}}{x - X_b + \sqrt{\omega^2 + (x - X_b)^2}}$$

$$I = \ln \frac{x + R_o}{x - X_b + R_b}$$

Derivatives within integrals of $\partial\phi/\partial x$, $\partial\phi/\partial\omega$ expressions

$$\frac{\partial 1/r}{\partial\omega} = -\frac{1}{r^2}\frac{\partial r}{\partial\omega} = -\frac{1}{r^2}\frac{\partial}{\partial\omega}\sqrt{\omega^2 + (x - \xi)^2} = -\frac{\omega}{r^3}$$

$$\frac{\partial 1/r}{\partial x} = -\frac{1}{r^2}\frac{\partial r}{\partial x} = -\frac{1}{r^2}\frac{\partial}{\partial x}\sqrt{\omega^2 + (x - \xi)^2} = -\frac{x - \xi}{r^3}$$

Combining terms

$$\frac{\partial\phi}{\partial t} = -\frac{BA_b}{2R_b}\frac{V}{1 - \frac{V}{c}\frac{x - X_b}{R_b}} + \frac{B^2}{2}\ln\left(\frac{x + R_o}{x - X_b + R_b}\right)$$

$$\frac{\partial \phi}{\partial \omega} = +\frac{BA_b}{2R_b} \frac{\frac{V}{c}\frac{\omega}{R_b}}{1 - \frac{V}{c}\frac{x - X_b}{R_b}} + \frac{B\omega}{2}\int_0^{X_b(\tau)} \left[A(\xi) - B(t - t_b)\right]\frac{1}{r^3}\, d\xi$$

$$\frac{\partial \phi}{\partial x} = +\frac{BA_b}{2R_b} \frac{\frac{V}{c}\frac{x - X_b}{R_b}}{1 - \frac{V}{c}\frac{x - X_b}{R_b}} + \frac{B}{2}\int_0^{X_b(\tau)} \left\{A(\xi) - B\left[t - t_b(\xi)\right]\right\}\frac{x - \xi}{r^3}\, d\xi$$

PROGRAMMING NOTE

The remaining integrals are difficult to evaluate numerically. For example, for x term define

$$I_x \equiv \int_0^{X_b(\tau)} \left\{A(\xi) - B\left[t - t_b(\xi)\right]\right\}\frac{x - \xi}{r^3}\, d\xi$$

Find an expression for $\partial I/\partial t$ and calculate I as a function of time by integrating $\partial I/\partial t$.

<u>Leibnitz's Rule</u>

$$\frac{\partial I_x}{\partial t} = \left(A_b - B\frac{R_b}{c}\right)\frac{x - X_b}{R_b^3}\left[\frac{\partial X_b(\tau)}{\partial t}\right] - B\int_0^{X_b(\tau)} \frac{x - \xi}{r^3}\, d\xi$$

but

$$\int_0^{X_b(\tau)} \frac{x - \xi}{r^3}\, d\xi = -\int_x^{x - X_b} \frac{y}{(\omega^2 + y^2)^{3/2}}\, dy = \left(\frac{1}{\sqrt{\omega^2 + y^2}}\right)_x^{x - X_b}$$

$$= \left(\frac{1}{R_b} - \frac{1}{R_o}\right)$$

and

$$\frac{\partial X_b(\tau)}{\partial t} = \frac{V}{1 - \frac{V}{c}\,\frac{x - X_b}{R_b}}$$

$$\star\therefore \frac{\partial I_x}{\partial t} = \left(A_b - B\,\frac{R_b}{c}\right)\frac{x - X_b}{R_b{}^3}\,\frac{V}{1 - \frac{V}{c}\,\frac{x - X_b}{R_b}} + B\left(\frac{1}{R_o} - \frac{1}{R_b}\right)$$

Similarly, for the ω term

$$I_\omega \equiv \omega \int_o^{X_b(\tau)} \left[A - B(t - t_b)\right]\frac{1}{r^3}\,d\xi$$

<u>Leibnitz's Rule</u>

$$\frac{\partial I_\omega}{\partial t} = \left(A_b - B\,\frac{R_b}{c}\right)\frac{\omega}{R_b{}^3}\left[\frac{\partial X_b(\tau)}{\partial t}\right] - B\omega \int_o^{X_b(\tau)} \frac{1}{r^3}\,d\xi$$

but

$$\int_o^{X_b(\tau)} \frac{d\xi}{r^3} = -\int_x^{x\ \ X_b} \frac{dy}{(\omega^2 + y^2)^{3/2}} = -\frac{1}{\omega^2}\left(\frac{y}{\sqrt{\omega^2 + y^2}}\right)_x^{x - X_b}$$

$$= \frac{1}{\omega^2}\left(\frac{x}{R_o} - \frac{x - X_b}{R_b}\right)$$

$$\frac{\partial X_b(\tau)}{\partial t} = \frac{V}{1 - \frac{V}{c}\,\frac{x - X_b}{R_b}}$$

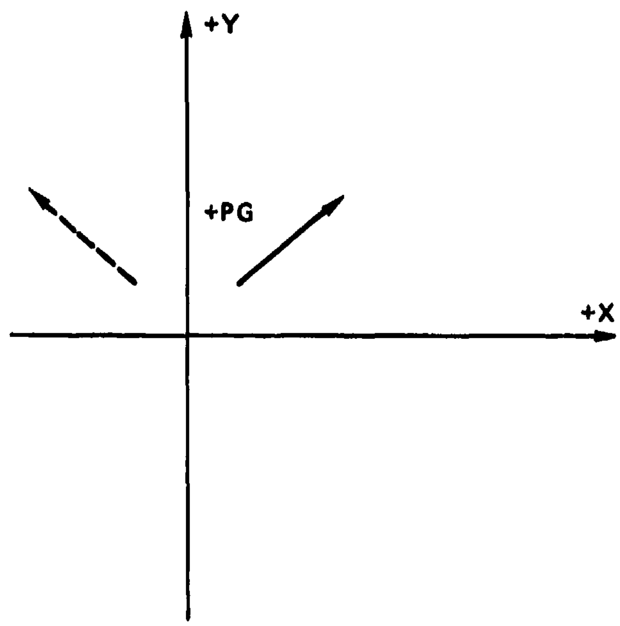
$$\bigstar\therefore \frac{\partial I_\omega}{\partial t} = \left(A_b - B\,\frac{R_b}{c}\right)\frac{\omega}{R_b{}^3}\,\frac{V}{1 - \frac{V}{c}\,\frac{x - X_b}{R_b}} - \frac{B}{\omega}\left(\frac{x}{R_o} - \frac{x - X_b}{R_b}\right)$$

Appendix B

UTILIZATION OF IMAGE LIMITER ARRAY

I. SAMPLE PROBLEM - SEMI-INFINITE FLUID

A. Pressure at a Point Within Fluid



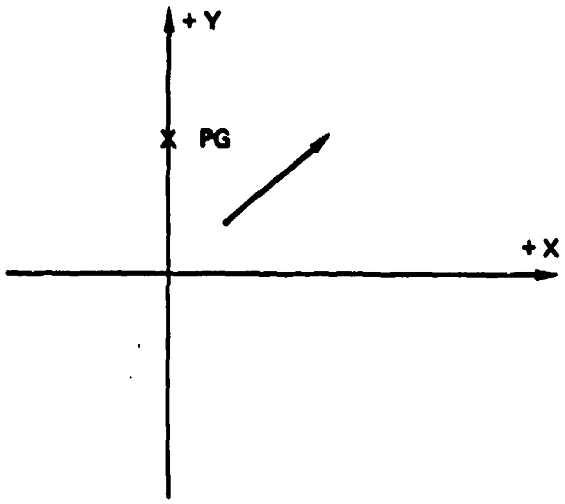
Fluid surface at X = 0, pressure at PG, image as shown.

Image limiter array:

LP(1), LP(2), LP(3) = 0,0,0
LM(1), LM(2), LM(3) = 1,0,0

Pressure at PG includes primary pressure wave plus reflection from free surface calculated from negative image.

B. Incident Pressure on Surface



Fluid surface at X = 0, pressure at PG, no images.

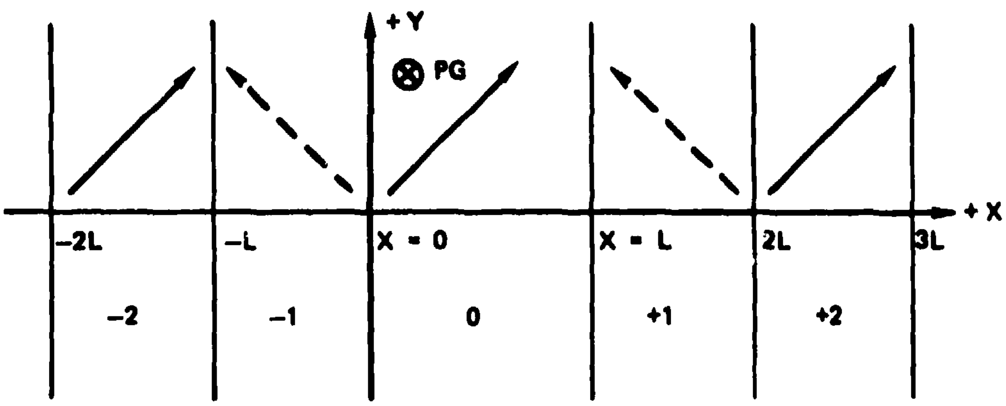
Image limiter array:

LP(1), LP(2), LP(3) = 0,0,0
LM(1), LM(2), LM(3) = 0,0,0

Gives incident pressure wave on surface X = 0.

II. SAMPLE PROBLEM - SEMI-INFINITE SLAB

A. Pressure at a Point Within Fluid



Fluid between planes X= 0 and X = L pressure calculated at point PG.

1. Source in cell 0 gives primary pressure.

2. Negative image at cell +1 gives reflection from surface at X = L.

3. Negative image at cell -1 gives reflection from surface at X = 0.

4. Image at cell +2 gives twice reflected wave from source in cell 0 to surface X = 0 to surface X = L to point PG.

5. Image at cell -2 gives twice reflected wave from source in cell 0 to surface X = L to surface X = 0 to point PG.

Number of images along the X axis increases the number of reflections which are accounted for. If pressure is to be calculated for time, T, the number of images, N, requires approximately

$$2N + 1 \geq \frac{cT}{L}$$

where c is the sound speed in the fluid.

NOTE. Computer running time is proportional to product NT for the semi-infinite slab.

NOTE. The free surface approximation for light structures gives increasingly inaccurate results for multiple reflections.

NOTE. Pressure from a given image source decays approximately with $1/R^2$ dependence so reflecting waves become progressively less important with increasing cell number.

Economics and accuracy indicate truncation of the number of images.

Image limiter array for illustrated example with twice reflected waves:

LP(1), LP(2), LP(3) = 2,0,0
LM(1), LM(2), LM(3) = 2,0,0

B. Incident Pressure on Surface at X = 0

Find images which contribute to incident pressure in sample problem IIA. Incident waves come from the right. Waves reflected from the surface X = 0 arise from images on the left. (If the incident and reflected waves were added, the result would be zero.) Therefore, the image array should be

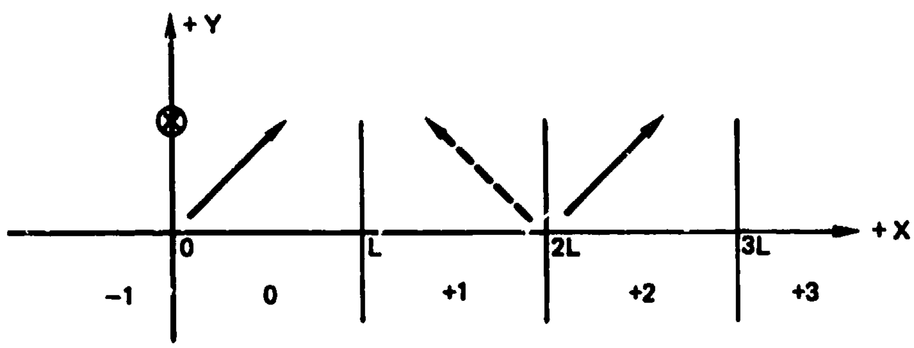


Image limiter array:

LP(1), LP(2), LP(3) = 2,0,0
LM(1), LM(2), LM(3) = 0,0,0

C. Incident Pressure on Surface at X = L

Same logic as example IIB. Incident waves, in this case, come from the left.

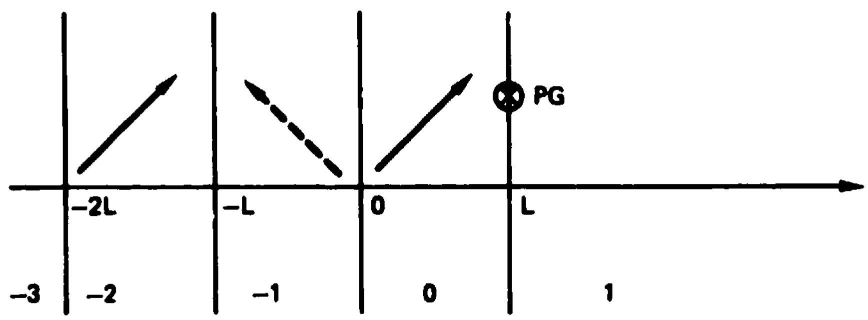


Image limiter array:

LP(1), LP(2), LP(3) = 0,0,0
LM(1), LM(2), LM(3) = 2,0,0

III. RECTANGULAR CROSS-SECTIONAL CYLINDER

A. Pressure Within Fluid

Extend logic of example IIA to two dimensions.

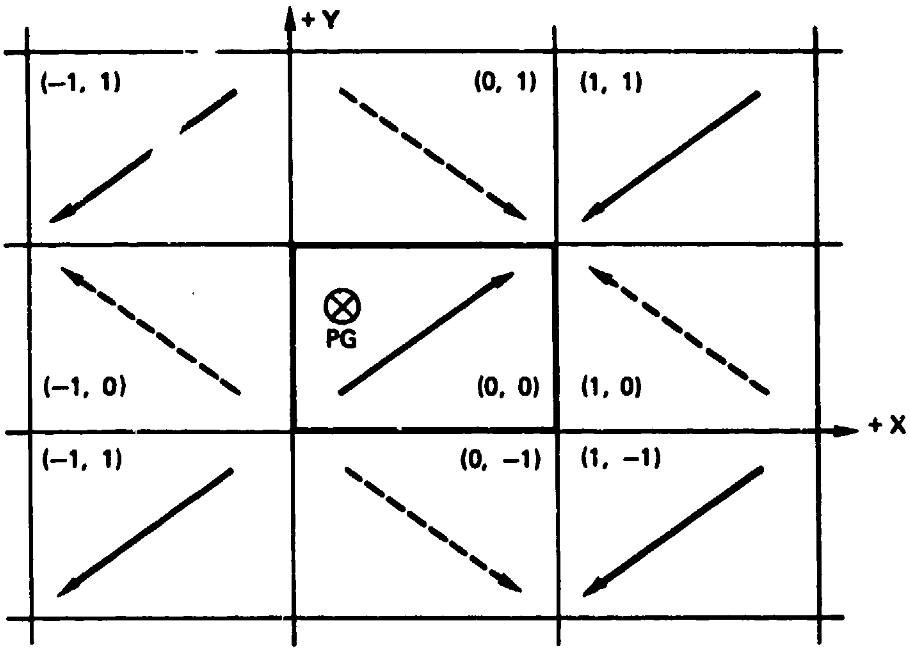


Image limiter array:

LP(1), LP(2), LP(3) = 1,1,0
LM(1), LM(2), LM(3) = 1,1,0

NOTE. The number of images required for time, T, with fluid volume dimension L is approximately:

$$2N + 1 \geq \left(\frac{cT}{L}\right)^2$$

Economics may dictate truncation of the number of images.

B. Incident Pressure at a Surface

Let the point be the surface Y = L. Referring to example IIIA, incident waves on this surface come from below; reflected waves come from above. Image array is then

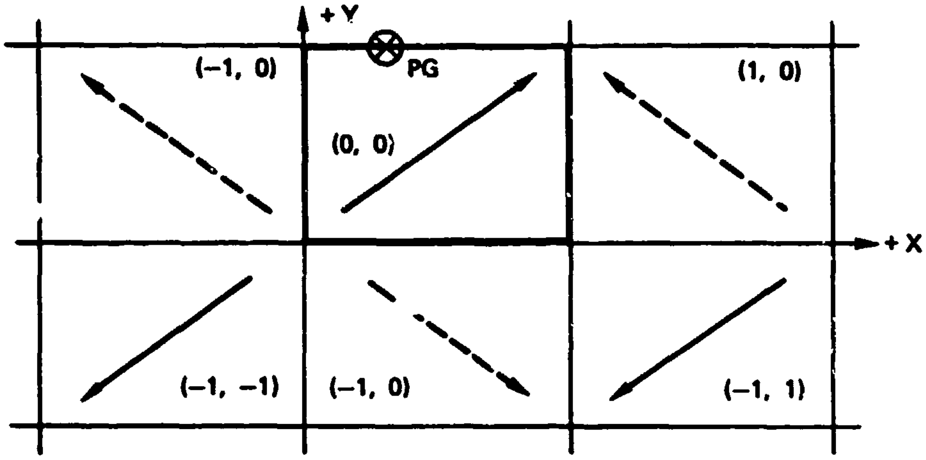


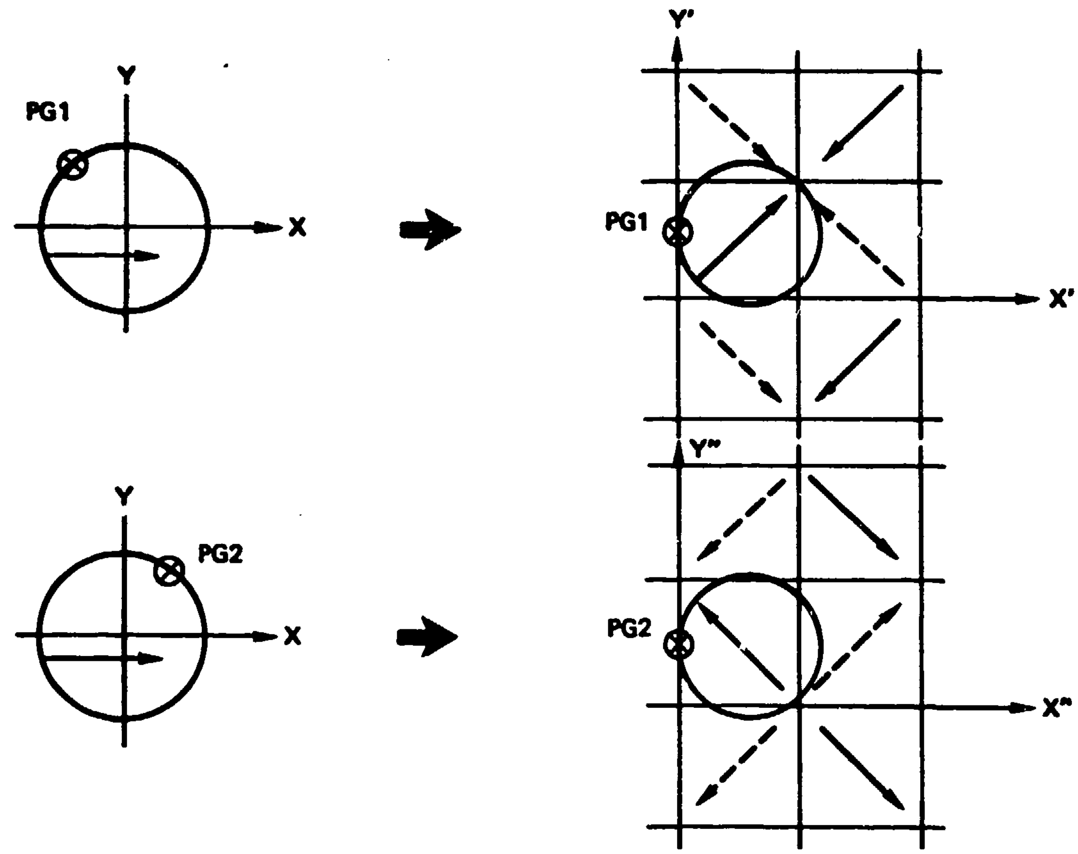
Image limiter array:

LP(1), LP(2), LP(3) = 1,0,0
LM(1), LM(2), LM(3) = 1,1,0

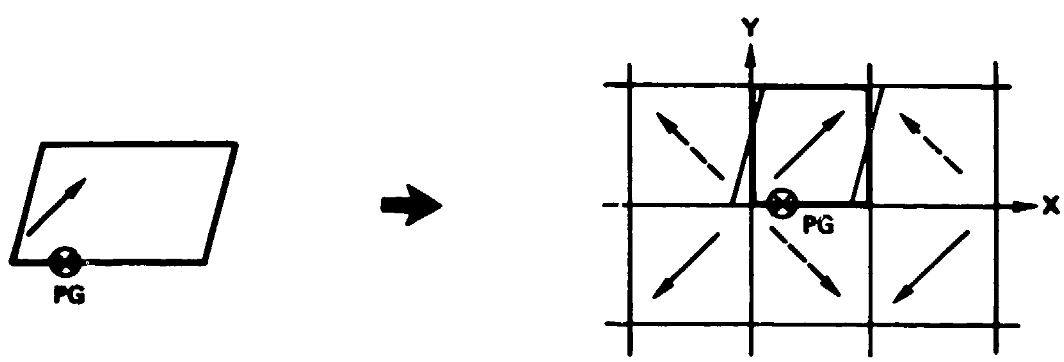
IV. NONRECTANGULAR VOLUMES

Nonrectangular volumes cannot be treated exactly using the method of images for wave reflections. Exact treatment is very difficult and computer codes are not available. The following suggest ways for *approximately* accounting for wave reflections in nonrectangular volumes. Incident pressures will be considered.

Circular cylinder: construct rectangular volume for each individual point on the surface.



A. Parallelogram



Obviously, the closer to rectangular shape the more accurate the results will be. The accuracy of this approximation has not been evaluated yet.

Appendix C

COORDINATE TRANSFORMATION

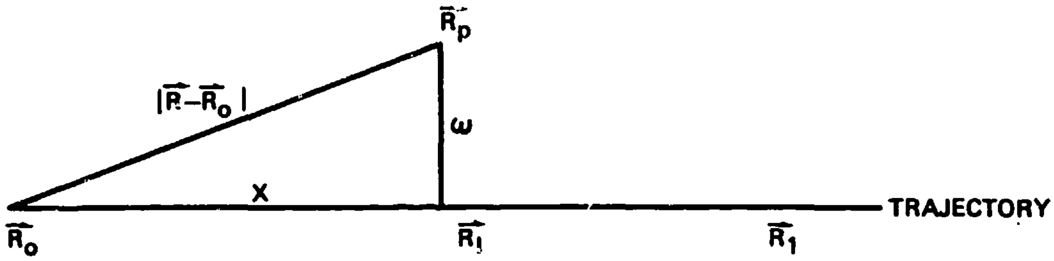
1. Entrance coordinates $(X_o, Y_o, Z_o) = \vec{R}_o$

2. Point on trajectory $(X_1, Y_1, Z_1) = \vec{R}_1$

3. Point in space $(X_p, Y_p, Z_p) = \vec{R}_p$

4. Cylindrical coordinates with respect to trajectory (x,ω)

Problem: Calculate (x,ω) for point $\vec{R}_p$ as a function of $\vec{R}_o$, $\vec{R}_1$, and $\vec{R}_p$.



$$x = (\vec{R} - \vec{R}_o) \cdot (\vec{R}_1 - \vec{R}_o) \Big/ \left|\vec{R}_1 - \vec{R}_o\right|$$

$$x = \frac{(X_p - X_o)(X_1 - X_o) + (Y_p - Y_o)(Y_1 - Y_o) + (Z_p - Z_o)(Z_1 - Z_o)}{r_1}$$

where

$$r_1 \equiv \left|\vec{R}_1 - \vec{R}_o\right| = \sqrt{(X_1 - X_o)^2 + (Y_1 - Y_o)^2 + (Z_1 - Z_o)^2}$$

If $r_o \equiv \left|\vec{R}_p - \vec{R}_o\right| = \sqrt{(X_p - X_o)^2 + (Y_p - Y_o)^2 + (Z_p - Z_o)^2}$

$$\omega = \sqrt{r_o^2 - x^2}$$

Problem given $\vec{U} = (U_x, U_\omega)$, find $\vec{U} = (U_x, U_y, U_z)$

Define unit vectors in (x, y, z) coordinates $\hat{X}, \hat{Y}, \hat{Z}$

Define unit vectors in x, ω coordinates $\hat{x}, \hat{\omega}$

Velocity components are:

$$U_x = U_x(\hat{x} \cdot \hat{X}) + U_\omega(\hat{\omega} \cdot \hat{X})$$

$$U_y = U_x(\hat{x} \cdot \hat{Y}) + U_\omega(\hat{\omega} \cdot \hat{Y})$$

$$U_z = U_x(\hat{x} \cdot \hat{Z}) + U_\omega(\hat{\omega} \cdot \hat{Z})$$

Unit vectors are

$$\hat{x} = \frac{\vec{R}_1 - \vec{R}_o}{r_1}$$

$$\hat{\omega} = \frac{\vec{R}_p - \vec{R}_I}{\omega}$$

where $R_I = R_o + (R_1 - R_o)\frac{x}{r_1} = (X_I\ Y_I, Z_I)$

$$U_x = U_x\left(\frac{X_1 - X_o}{r_1}\right) + U_\omega\left(\frac{X_p - X_I}{\omega}\right)$$

$$U_y = U_x\left(\frac{Y_1 - Y_o}{r_1}\right) + U_\omega\left(\frac{Y_p - Y_I}{\omega}\right)$$

$$U_z = U_x\left(\frac{Z_1 - Z_o}{r_1}\right) + U_\omega\left(\frac{Z_p - Z_I}{\omega}\right)$$

where

$$X_I = X_o + \left(X_1 - X_o\right)\frac{x}{r_1}$$

$$Y_I = Y_o + \left(Y_1 - Y_o\right)\frac{x}{r_1}$$

$$Z_I = Z_o + \left(Z_1 - Z_o\right)\frac{x}{r_1}$$

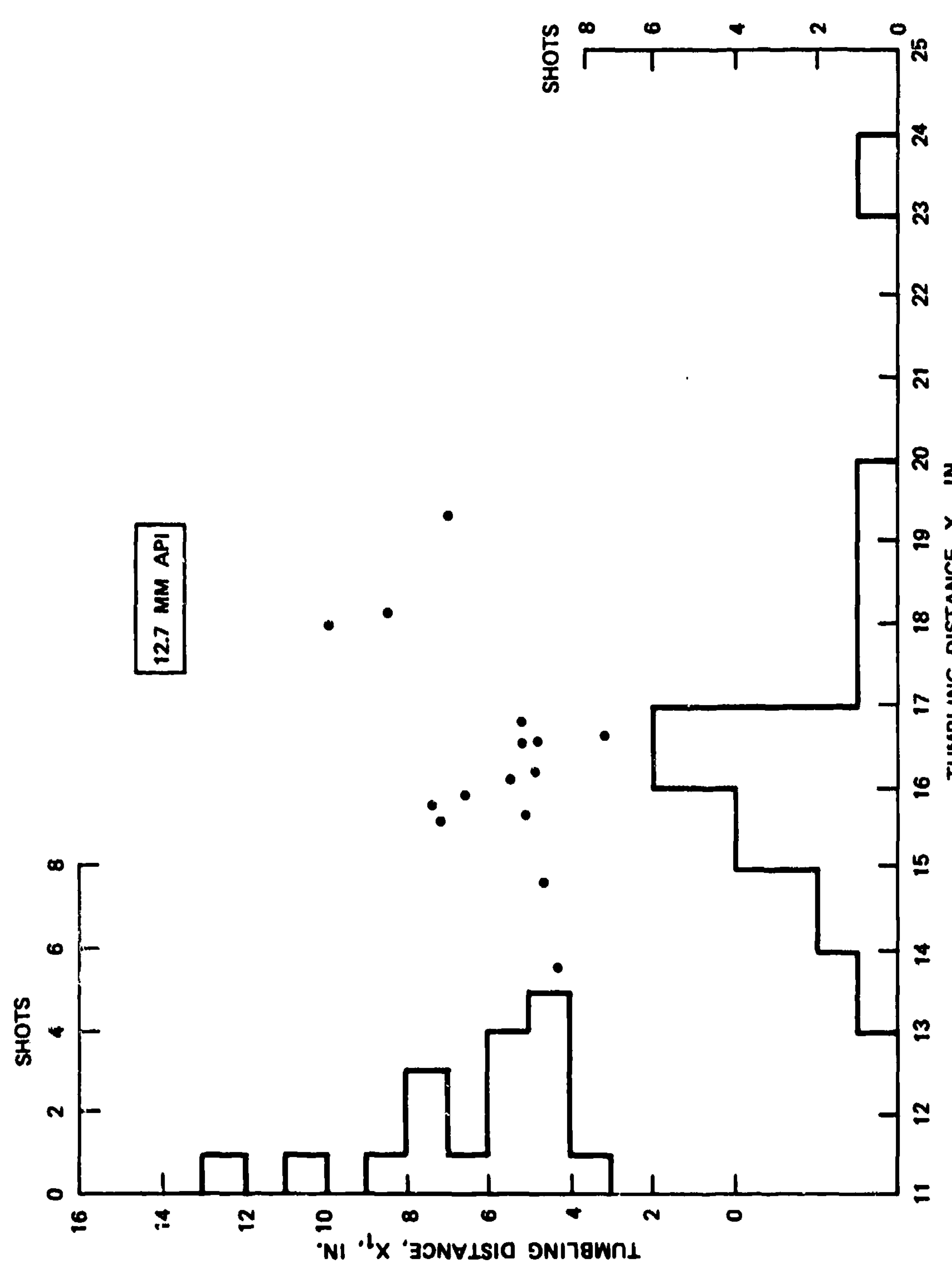
Appendix D

RECOMMENDED BULLET CONSTANTS

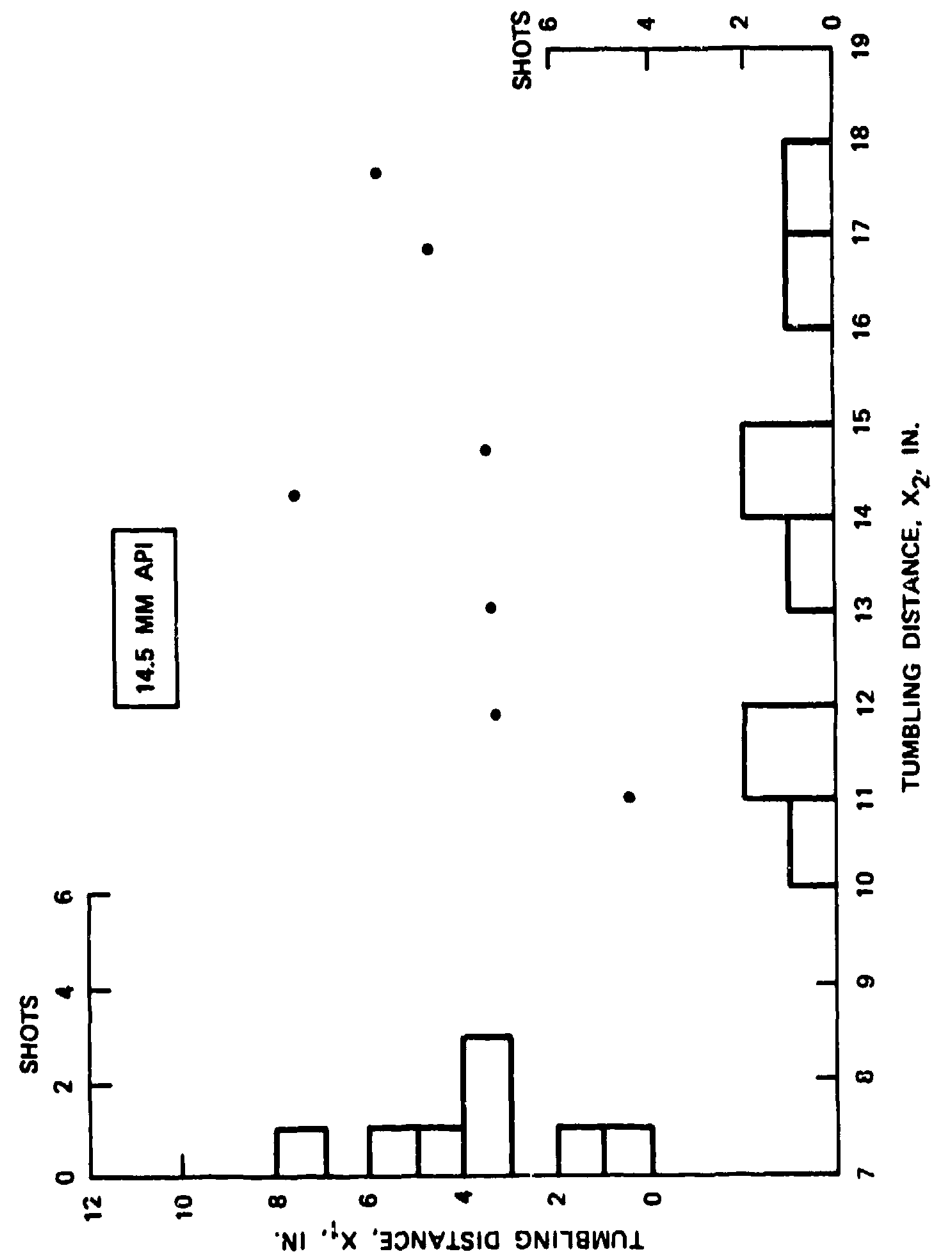
Constants	.30 caliber	.50 caliber	12.7 mm	14.5 mm
Bullet weight	165.7 grains	622-649 grains	746 grains	963 grains
Bullet dimensions	Diameter: 0.308 in. Length: 1.39 in.	Diameter: 0.510 → 0.511 in. Length: 2.31 in.	Diameter: 0.510 → 0.511 in. Length: 2.5 in.	Diameter: 0.586 → 0.587 in. Length: 2.6 in.
Penetrator weight	80 → 81.2 grains	375 grains	448/449 grains	655 grains
Penetrator dimensions	Diameter: 0.244 → 0.245 in. Length: 1.08 in.	Diameter: 0.426 → 0.427 in. Length: 1.8 in.	Diameter: 0.427 in. Length: 2.07 in.	Diameter: 0.4889 in. Length: 2.075 in.
Jacket weight	84.5 → 85.7 grains	247 → 274 grains includes incendiary	297 → 298 grains includes incendiary	293.21 grains excludes incendiary
Jacket dimensions	Same as bullet dimensions	Same as bullet dimensions	Same as bullet dimensions	Same as bullet dimensions
Bullet/jacket projected area, untumbled	0.0745 in^2	0.2042 → 0.2050 in.	0.2042 → 0.2050 in.	0.2697 → 0.2906 in.
Bullet/jacket projected area, untumbled	0.31732 in^2	0.73625 in^2	1.03772 in^2	1.322 in^2
Penetrator projected area, untumbled	0.0468 → 0.0471 in^2	0.1425 → 0.1432 in^2	0.1432 in^2	0.18773 in^2
Penetrator projected area, tumbled	0.2601 in^2	0.59830 in^2	0.700214 in^2	1.05 in^2
Bullet projected area, stern-first	0.0314 in^2	0.1121 in^2	0.0855 in^2	0.12566 in^2
C_D of bullet, normal attitude	0.10	0.05	0.05	0.10
C_D of bullet, tumbled attitude	0.60	0.30	0.30	0.30
C_D of penetrator, normal attitude	0.10	0.05	0.05	0.10
C_D of penetrator, tumbled attitude	0.60	0.30	0.30	0.30
C_D of jacket, tumbled attitude	1.0	1.0	1.0	1.0
C_D of bullet, stern-first attitude	0.82	0.82	0.82	0.82

Appendix E

TUMBLING BEHAVIOR OF 12.7 AND 14.5 MM API FROM FOOTNOTE 2



Tumbling Distance Distribution; 0 Degree Obliquity, 0 Degree Yaw.



Tumbling Distance Distribution; 0 Degree Obliquity, 0 Degree Yaw.